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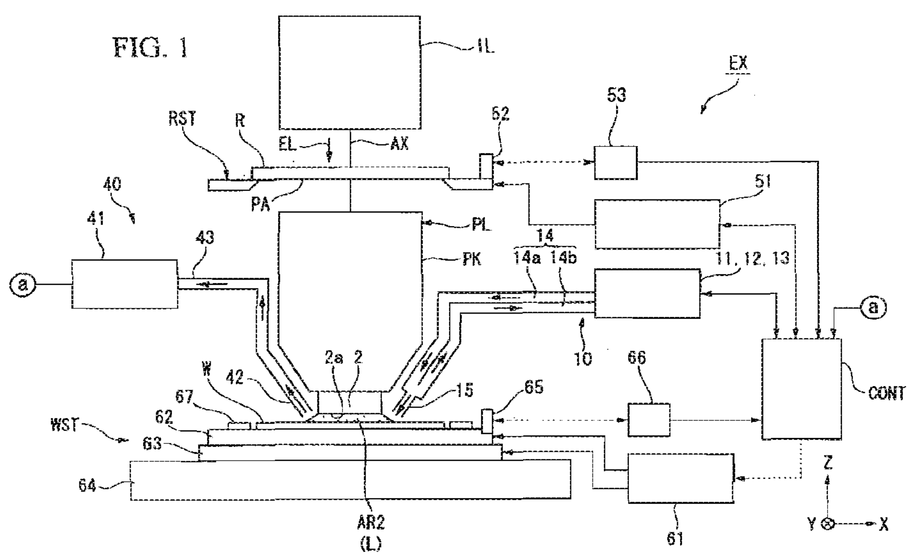
(54) **EXPOSURE APPARATUS, EXPOSURE METHOD, AND METHOD FOR MANUFACTURING DEVICE**

(57) An exposure apparatus (EX) that: projects pattern (PA) images onto a substrate (W) via liquid (L) and a projection optical system (PL), the liquid (L) forming a liquid immersion region (AR2) between the projection optical system (PL) and the substrate (W); and exposes the substrate (W). The apparatus (EX) has: a liquid-supplying-section (15) that supplies the liquid (L) onto the substrate (W); a first pipe section (14a) that introduces the liquid (L) to the liquid-supplying-section (15); and a second pipe section (14b), connected to the first pipe section (14a), that collects the liquid (L) not being supplied to the liquid-supplying-section (15) from the first pipe section (14a). By doing this, it is possible to provide a liquid-immersion exposure apparatus (EX) having a liquid-supplying-mechanism, exposure method, and a method for manufacturing devices so as to: restrict the temperature of the liquid (L), supplied between the projection optical system (PL) and the substrate, from varying; and prevent contaminants from invading into the liquid (L).

FIG. 1



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Description

TECHNICAL FIELD

[0001] The present invention relates to a technology with respect to an exposure apparatus that is used in transcription steps of lithographic steps for manufacturing highly-integrated semiconductor circuit elements.
Priority is claimed on Japanese Patent Application No. 2003-362279, filed October 22, 2003, the content of which is incorporated herein by reference.

BACKGROUND ART

[0002] A semiconductor device or liquid crystal display device is manufactured by technique known as photolithography, in which a pattern formed on a mask is transferred onto a photosensitive substrate. The exposure apparatus used in this photolithography process has a mask stage that supports a mask and a substrate stage that supports a substrate, and it transfers a mask pattern onto a substrate via a projection optical system while sequentially moving the mask stage and the substrate stage.
In recent years, there has been a demand for higher resolution of the projection optical system in order to respond to the further advances in terms of higher integration of the device pattern. As the exposure wavelength to be used becomes shorter, the resolution of the projection optical system becomes higher. As the numerical aperture of the projection optical system becomes larger, the resolution of the projection optical system becomes higher. Therefore, the exposure wavelength which is used for the exposure apparatus is shortened year by year, and the numerical aperture of the projection optical system is increased as well. The exposure wavelength, which is dominantly used at present, is 248 nm of the KrF excimer laser. However, the exposure wavelength of 193 nm of the ArF excimer laser, which is shorter than the above, is also practically used in some situations. When the exposure is performed, the depth of focus (DOF) is also important in the same manner as the resolution. The resolution R and the depth of focus δ are represented by the following expressions respectively.

$$R = k_1 \cdot \lambda / NA \qquad (1)$$

$$\delta = \pm k_2 \cdot \lambda / NA^2 \qquad (2)$$

In the expressions, λ represents the exposure wavelength, NA represents the numerical aperture of the projection optical system, and k_1 and k_2 represent the process coefficients. According to the expressions (1) and (2), the following fact is appreciated. That is, when the exposure wavelength λ is shortened and the numerical aperture NA is increased in order to enhance the resolution R, then the depth of focus δ is narrowed.

[0003] If the depth of focus δ is too narrow, it is difficult to match the substrate surface with respect to the image plane of the projection optical system. There is concern that the margin is insufficient during the exposure operation. Accordingly, the liquid immersion method has been suggested, which is disclosed, for example, in PCT International Publication No. WO99/49504 as a method for substantially shortening the exposure wavelength and widening the depth of focus. In this liquid immersion method, the space between the lower surface of the projection optical system and the substrate surface is filled with a liquid such as water or any organic solvent so that the resolution is improved and the depth of focus is magnified about n times by utilizing the fact that the wavelength of the exposure light beam in the liquid is 1/n as compared with that in the air (n represents the refractive index of the liquid, which is about 1.2 to 1.6 in ordinary cases).
With respect to the water and the organic solvent filled between the lower surface of the projection optical system and the substrate surface, temperature must be controlled strictly. This is because, if the temperature of the liquid varies, the refractive index of the liquid varies; thereby, the wavelength of the exposure light beam varies in the liquid; thus, a defect occurs due to the varied exposure light beam. More specifically, the temperature of the liquid must be controlled to be in a range of ±0.01°C with respect to a predetermined temperature of the liquid, and the temperature-controlled liquid must be supplied onto the substrate continuously.

DISCLOSURE OF INVENTION

PROBLEMS TO BE SOLVED BY THE INVENTION

[0004] However, the temperature of the liquid may be affected by ambient temperature therearound if pipes which supply the liquid from a temperature control device (thermostat reservoir) to liquid-supplying-nozzles are long. Also, if the liquid supply is stopped when a wafer is exchanged, the temperature of the liquid existing in the pipes varies; therefore, there is a problem in that the exposure process cannot be restarted immediately even if the liquid supply is restarted because the temperature of the liquid in the liquid immersion region is not in the above temperature range.
In addition, there is possibility that contaminants may invade the liquid from ports of the pipes. In particular, if the exposure apparatus is stopped for a long time for purposes such as repair and inspection, there is possibility that bacteria will grow in the liquid existing in the pipes. Therefore, there is a problem with respect to not only micro-patterning but also operation of the exposure apparatus.

[0005] The present invention was conceived in view of

the above circumstances, and an object thereof is to provide a liquid-immersion exposure apparatus having a liquid-supplying-mechanism, exposure method, and a method for manufacturing devices so as to: restrict temperature of the liquid supplied between the projection optical system and the substrate from varying; and prevent contaminants from invading the liquid.

MEANS FOR SOLVING THE PROBLEMS

[0006] In the exposure apparatus, the exposure method, and the method for manufacturing devices according to the present invention, the following members are employed in order to overcome the above problems.

A first invention provides an exposure apparatus (EX) that: projects pattern (PA) images onto a substrate (W) via liquid (L) and an projection optical system (PL), the liquid (L) forming a liquid immersion region (AR2) between the projection optical system (PL) and the substrate (W); and exposes the substrate (W), the apparatus having: a liquid-supplying-section (15) that supplies the liquid (L) onto the substrate (W); a first pipe section (14a, 32a) that introduces the liquid (L) to the liquid-supplying-section (15); and a second pipe section (14b, 32b), connected to the first pipe section (14a, 32a), that collects the liquid (L), that is not supplied to the liquid-supplying-section (15) from the first pipe section (14a, 32a). According to this invention, a greater amount of liquid than that supplied onto the substrate is introduced into the first pipe section (14a, 32a), and the rest of the liquid is collected via the second pipe section (14b, 32b). Therefore, the liquid does not stop in the pipe sections when, e.g., the wafer is exchanged; thus, the temperature of the liquid hardly varies and contaminants hardly invade into the liquid.

[0007] Also, in the exposure apparatus in which at least a portion of the liquid (L) circulates in the first pipe section (14a, 32a) and the second pipe section (14b, 32b), it is possible to prevent the temperature of the liquid from varying and the contaminants from invading into the liquid while minimizing the quantity of liquid-to-be-consumed.

Also, in the exposure apparatus having a thermostat reservoir (12) which: maintains the temperature of the liquid (L) approximately constant; and supplies the liquid (L) to the first pipe section (14a, 32a), it is possible to supply the liquid having an approximately constant temperature onto the substrate from the liquid-supplying-section (15).

Also, in the present invention: the exposure apparatus further has temperature measuring sections that measure the temperature of the liquid (L) supplied onto the substrate (W); the temperature control sections are disposed at least in one of the first pipe section (14a, 32a) and the liquid-supplying-section (15); and the thermostat reservoir (12) controls the temperature of the liquid in accordance with measurement results measured by the temperature measuring sections.

Also, in the exposure apparatus in which the second pipe section (14b, 32b) is connected to the thermostat reservoir (12), temperature of the collected liquid is adjusted and reintroduced into the first pipe section (14a, 32a). It is possible to supply the liquid having an approximately constant temperature onto the substrate and reduce running costs.

Also, in the exposure apparatus further has a refining device (11) that refines the liquid (L), it is possible to supply bacterium-free and contaminant-free liquid onto the substrate.

Also, in the exposure apparatus in which the second pipe section (14b, 32b) is connected to the refining device, and the collected liquid is refined by the refining device, it is possible to eliminate impurities and bacterium from the circulating liquid.

Also, in the exposure apparatus in which the first pipe section (32a) and the second pipe section (32b) form a double pipe (32) so that the second pipe section (32b) is formed around the first pipe section (32a) together, the collected liquid flows around the liquid supplied onto the substrate, and the collected liquid serves as a thermal insulating member; therefore, it is possible to restrict variations in the temperature of the supplied liquid.

Also, in the exposure apparatus in which the liquid-supplying-section (15) has an aperture mechanism (16, 34) that adjusts quantity of the liquid (L) supplied onto the substrate (W), it is possible to adjust the quantity of liquid supplied onto the substrate desirably.

[0008] A second invention is an exposure method including steps of: forming a liquid immersion region (AR2) by supplying the liquid (L) between the projection optical system (PL) and the substrate (W); projecting the pattern (PA) images onto the substrate (W) via the supplied liquid (L) and the projection optical system (PL); and exposing the substrate (W), the method including: flowing the liquid (L); and supplying at least a portion of the flowing liquid (L) onto the substrate (W). In this invention, the liquid does not stop in the pipe sections; therefore, the temperature of the liquid hardly varies and impurities hardly invade into the liquid.

In the present invention, the first pipe section (32a), the second pipe section (32b), and the liquid-supplying-sections are connected by three-way-valves.

[0009] Also, in the exposure method further including steps of: stopping supplying the liquid (L) onto the substrate (W); and flowing all the liquid (L), the liquid does not stop in the pipe sections even if supplying the liquid is stopped when, e.g., the wafer is exchanged. Therefore, the temperature of the liquid hardly varies and impurities hardly invade into the liquid.

Also, in the exposure method further including steps of: collecting the liquid (L) which has not been supplied onto the substrate (W); controlling the temperature of the collected liquid (L); and supplying the temperature-controlled liquid (L), it is possible to minimize quantity of the liquid-to-be-consumed while maintaining the temperature of liquid-to-be-supplied approximately constant by circulating the temperature-controlled liquid (L).

[0010] A third invention is a device-manufacturing

method including lithographic steps in which the method uses the exposure apparatus (EX) in the lithographic steps according to the first invention. According to this invention, the temperature can be maintained approximately constant, and the impurity-and-bacterium-free liquid is used; therefore, it is possible to manufacture devices having micro-patterns stably.

EFFECTS OF THE INVENTION

[0011] According to the present invention, the following effects can be realized.

The first invention provides an exposure apparatus that: projects pattern images onto a substrate via liquid and a projection optical system, the liquid forming a liquid immersion region between the projection optical system and the substrate; and exposes the substrate, the apparatus including: a liquid-supplying-section that supplies the liquid onto the substrate; a first pipe section that introduces the liquid to the liquid-supplying-section; and a second pipe section, connected to the first pipe section, that collects the liquid which has not been supplied to the liquid-supplying-section from the first pipe section. By doing this, the liquid does not stop in the pipe sections; therefore, it is possible to prevent the temperature of the liquid from varying and form micro-patterns stably via the liquid disposed in the liquid immersion region. Also, the liquid does not stop; therefore; it is possible to restrict generation of bacterium.

[0012] Also, since at least a portion of the liquid circulates in the first pipe section and the second pipe section, it is possible to prevent the temperature of the liquid from varying and impurities from invading while minimizing the quantity of liquid-to-be-consumed. Thus, it is possible to form micro-patterns via the liquid in the liquid immersion region stably and at low cost.

Also, since the exposure apparatus has a thermostat reservoir which: maintains the temperature of the liquid approximately constant; and supplies the liquid to the first pipe section, it is possible to supply the liquid having an approximately constant temperature onto the substrate from the liquid-supplying-section and it is possible to restrict refractive index of exposure light beam from varying.

Also, since the second pipe section is connected to the thermostat reservoir; therefore, it is possible to supply the liquid having an approximately constant temperature onto the substrate while reducing the running cost; and to prevent refractive index of the exposure light beam from varying at low cost.

Also, since the exposure apparatus has the refining device that refines the liquid; therefore, it is possible to supply impurity-free and bacterium-free liquid onto the substrate; and to form micro-patterns via the liquid in the immersion liquid region stably and reliably.

Also, since the second pipe section is connected to the refining device so that the collected liquid is refined in the refining device, it is possible to eliminate impurities and bacterium from the circulating liquid; and to form micro-patterns via the liquid in the immersion liquid region stably, reliably, and at low cost.

Also, since the first pipe section and the second pipe section form a double pipe so that the second pipe section is formed around the first pipe section together, it is possible to restrict the temperature of the supplied liquid from varying by adopting a simple structure, i.e., at a low cost.

Also, since the liquid-supplying-section has the aperture mechanism that adjusts the quantity of liquid supplied onto the substrate, it is possible to adjust the quantity of liquid supplied onto the substrate adequately; and to form micro-patterns stably via the liquid disposed in the liquid immersion region.

[0013] The second invention is an exposure method including steps of: forming a liquid immersion region by supplying liquid between a projection optical system and a substrate; projecting pattern images onto the substrate via the liquid and the projection optical system; and exposing the substrate, the method including: flowing the liquid; and supplying at least a portion of the flowing liquid onto the substrate. By doing this, the liquid does not stop in the pipe sections; therefore, the temperature of the liquid hardly varies and impurities hardly invade; thus, micro-patterns can be formed reliably via the liquid disposed in the liquid immersion region.

[0014] Also, since the exposure method further includes steps of: stopping supplying the liquid onto the substrate; and flowing all the liquid, the temperature of the liquid hardly varies and impurities hardly invade into the liquid even if supplying the liquid stops so as to exchange wafers, etc. In addition, it is not necessary to: adjust the temperature of the liquid; and eliminate contaminants after exchanging wafers; thus, it is possible to restart the exposure steps immediately after exchanging the wafers.

Also, since the exposure method further includes steps of: collecting the liquid which has not been supplied onto the substrate; controlling the temperature of the collected liquid; and supplying the temperature-controlled liquid, it is possible to minimize the quantity of liquid-to-be-consumed while maintaining the temperature of liquid-to-be-supplied approximately constant; and to form micro-patterns via the liquid disposed in the liquid immersion region stably at low cost.

[0015] The third invention is a device-manufacturing method including lithographic steps in which the method uses the exposure apparatus according to the first invention in the lithographic steps. According to this invention, the temperature can be maintained approximately constant, and the impurity-free and bacterium-free liquid is used; therefore, the product yield increases, and it is possible to manufacture devices having micro-patterns stably at low cost.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] FIG 1 is a schematic diagram of a general struc-

ture of an exposure apparatus.

FIG. 2 is a schematic diagram of a liquid-supplying-mechanism in detail.
FIG. 3A shows an arrangement of liquid-supplying-nozzles in the liquid-supplying-mechanism and liquid-collecting-nozzles in a liquid-collecting-mechanism.
FIG. 3B shows an arrangement of liquid-supplying-nozzles in the liquid-supplying-mechanism and liquid-collecting-nozzles in a liquid-collecting-mechanism:
FIG. 4 is a schematic view showing the liquid-supplying-mechanism in which a part of pipe sections are formed by double pipes.
FIG. 5 is a schematic view showing a different embodiment of the liquid-supplying-mechanism.
FIG. 6 shows steps of manufacturing semiconductor devices.

EXPLANATION OF REFERENCE NUMERALS

[0017] 11: ultra pure water device (refining device)

12: thermostat reservoir
14a: sending-side-pipe (first pipe)
14b: returning-side-pipe (second pipe)
15: supply-side-nozzle (liquid-supplying-section)
16: three-way-valve (aperture mechanism)
32a: inner pipe (first pipe)
32b: outer pipe (second pipe)
34: control valve (aperture mechanism)
AR2: liquid immersion region
L: liquid
W: wafer (substrate)
R: reticle (mask)
PA: pattern
PL: projection optical system
EX: exposure apparatus

BEST MODE FOR CARRYING OUT THE INVENTION

[0018] Embodiments of the present invention, e.g., an exposure apparatus, an exposure method, and a method for manufacturing a device, are explained with reference to the drawings as follows.
FIG. 1 is a schematic diagram of a general structure of an embodiment of the exposure apparatus according to the present invention. In FIG 1, an exposure apparatus EX has: a reticle stage RST that supports a reticle (mask) R having device patterns PA formed thereon; a wafer stage WST that supports a wafer (substrate) having a photosensitive material, e.g., photo-resist formed thereon; an illuminating optical system IL that illuminates a reticle R by emitting an exposure light beam EL; a projection optical system PL that projects pattern (PA) images of the reticle R by illuminating the exposure light beam EL onto the wafer W; and a control device CONT that controls overall operations of the exposure apparatus EX integrally.
In the present embodiment, the exposure apparatus EX is explained with reference to, e.g., a scanning exposure apparatus (so-called a scanning stepper) which exposes the patterns PA, formed on the reticle R, onto the wafer W by moving the reticle R and the wafer W in different (reverse) directions with respect to a scanning direction synchronously. Also, in the following explanations, a Z axis direction indicates a direction coinciding with an optical axis AX of the projection optical system PL. An X axis direction indicates a (scanning) direction in which the reticle R and the wafer W moves synchronously in a plane orthogonal with respect to the Z axis direction. A Y axis direction indicates a (non-scanning) direction orthogonal with respect to the Z axis direction and the X axis direction.
In addition, θX indicates a rotational direction around the X axis. θY indicates a rotational direction around the Y axis. θZ indicates a rotational direction around the Z axis.
[0019] Also, the exposure apparatus EX is a liquid immersion exposure apparatus using a liquid immersion method in order to: improve resolution by shortening exposure wavelength substantially; and increase depth of focus substantially. The exposure apparatus EX has: a liquid-supplying-mechanism 10 that supplies the liquid L onto the wafer W; and a liquid-collecting-mechanism 40 that collects the liquid L on the wafer W.
The exposure apparatus EX forms a liquid immersion region AR2 on a part of the wafer W including a projection region AR1 (see FIG. 3) on the projection optical system PL by the liquid L supplied from the liquid-supplying-mechanism 10 while at least transferring the image of the pattern PA of the reticle R onto the wafer W. More specifically, the exposure apparatus EX: fills the liquid L in a space, formed between an optical element 2 and the wafer W, at an tip end (bottom end) of the projection optical system PL; projects the image of the pattern PA of the reticle R onto the wafer W via the liquid L and the projection optical system PL; and exposes the wafer W. The liquid L in the liquid immersion region AR2 can be refreshed by: supplying the liquid L from the liquid-supplying-mechanism 10 to the liquid immersion region AR2; and collecting the liquid L disposed in the liquid immersion region AR2 by the liquid-collecting-mechanism 40; thus, contamination of the liquid L can be strictly prevented, and the temperature of the liquid L can be strictly controlled.
In the present embodiment, pure water is used as the liquid L. Various rays, e.g.: ultraviolet emission lines (e.g., g-line, h-line, and i-line) emitted from a mercury lamp; deep ultra violet rays (DUV rays), e.g., KrF excimer laser beam at a wavelength of 248 nm; and vacuum ultra violet rays (VUV rays), e.g., ArF excimer laser beam at wavelength of 193 nm, can be transmitted through pure water.
[0020] The illuminating optical system IL, illuminating the reticle R supported by the reticle stage RST by the exposure light beam EL, has: a light source for exposure;

an optical integrator for uniforming the intensity of illumination of the light flux emitted from a light source; a condenser lens for condensing the exposure light beam EL emitted from the optical integrator; a relay lens system; a variable perspective aperture for setting an illumination region illuminated by the exposure light beam EL on the reticle R in a slit manner; etc. (each member is not shown in the drawings). The illumination optical system IL illuminates a predetermined portion of the illumination region on the reticle R with light beam EL which has uniform illumination.

With respect to the exposure light beam EL emitted from the illumination optical system IL, various rays can be used, e.g.: deep ultra violet rays (DUV rays), e.g., ultra violet emission lines (e.g., g-line, h-line, and i-line) emitted from a mercury lamp and KrF excimer laser beam at a wavelength of 248 nm; and vacuum ultra violet rays (VUV rays), e.g., ArF excimer laser beam at a wavelength of 193 nm and F_2 laser beam at a wavelength of 157 nm. ArF excimer laser is used in the present embodiment.

[0021] The reticle stage RST, supporting the reticle R, is: movable two-dimensionally in an X-Y plane orthogonal with respect to the optical axis AX of the projection optical system PL; and rotatable around a θZ axis by fine pitches. The reticle stage RST is driven by a reticle stage driving section 51, e.g., a linear motor, controlled by the control device CONT.

A movable mirror 52 is disposed on the reticle stage RST. Also, a laser interferometer 53 is disposed corresponding to the movable mirror 52. With respect to the reticle R disposed on the reticle stage RST, the laser interferometer 53 measures: two-dimensional positions; and rotation angles, on real-time bases, and the measurement results are outputted to the control device CONT.

The control device CONT sets positions of the reticle R supported on the reticle stage RST by driving the reticle stage driving section 51 in accordance with the measurement results outputted from the laser interferometer 53.

[0022] The projection optical system PL projects/exposes the pattern PA of the reticle R onto the wafer W at a predetermined projection magnification β. The projection optical system PL is constituted by a plurality of optical elements including an optical element 2. These optical elements are disposed at an end portion, near the wafer W, of the projection optical system PL. These optical elements are supported by a barrel PK. In the present embodiment, the projection optical system PL has a reduction system having the projection magnification β, e.g., 1/4 or 1/5. The projection optical system PL may be any one of the 1x magnification system and the magnifying system. The optical element 2, disposed at the end of the projection optical system PL, is disposed detachably (exchangeably) with respect to the barrel PK. The liquid L disposed in the liquid immersion region AR2 makes contact with the optical element 2.

The optical element 2 is made of fluorite. Fluorite has a high affinity for water. Therefore, the liquid L can make tight contact with substantially the entire surface of a liquid contact surface 2a of the optical element 2. That is, the liquid (water) L having high affinity for the liquid contact surface 2a of the optical element 2 is supplied. Therefore, the highly tight contact is effected between the liquid L and the liquid contact surface 2a of the optical element 2; thus, the optical path between the optical element 2 and the wafer W can be reliably filled with the liquid L. The optical element 2 may be made of silica having a high affinity for water. Water-affinity (liquid affinity) may be imparted to the liquid contact surface 2a of the optical element 2A so as to further enhance the affinity for the liquid L.

[0023] The wafer stage WST, supporting the wafer W, is provided with: a Z stage 62 for supporting the wafer W via a wafer holder; a XY stage 63 for supporting the Z stage 62; and a base 64 for supporting the XY stage 63. The wafer stage WST is driven by a wafer stage driving section 61, e.g., a linear motor, controlled by the control device CONT. The wafer stage driving section 61 drives the Z stage 62 so that positions, i.e., focusing positions of the wafer W supported by the Z stage 62 with respect to: the Z axis direction; θX direction; and θY direction are fixed.

The wafer stage driving section 61, driving the XY stage 63, sets positions of the wafer W with respect to the XY direction (i.e., a direction substantially parallel with respect to an image surface of the projection optical system PL). The Z stage and the XY stage may be formed unitarily so as to provide XYZ stage which has six-degrees of freedom.

A movable mirror 65 is disposed on the wafer stage WST (Z stage 62). A laser interferometer 66 is disposed corresponding to the movable mirror 65. With respect to the wafer W disposed on the wafer stage WST, the laser interferometer 66 measures: two-dimensional positions; and rotation angles, on real-time bases, and the measurement results are outputted to the control device CONT.

The control device CONT sets positions of the wafer W supported on the wafer stage WST by driving the wafer stage driving section 61 in accordance with the measurement results outputted from the laser interferometer 66. Based on the measurement results outputted from the laser interferometer 66, the control device CONT controls so that: the Z stage 62 to control focusing positions and inclination angles with respect to the wafer W, and to coincide a surface of the wafer W with the image surface of the projection optical system PL using an auto-focus method and auto-leveling method; and the XY stage 63 to set positions of the wafer W with respect to the X axis direction and the Y axis direction.

[0024] An auxiliary plate 67, surrounding the wafer W, is disposed on the wafer stage WST (Z stage 62). The auxiliary plate 67 has a flat surface that has approximately the same height as that of the surface of the wafer W supported by the wafer holder. In this arrangement, a gap of about 1 to 2 mm is provided between an edge of

the wafer W and the auxiliary plate 67. However, the liquid L scarcely flows into the gap owing to surface tension of the liquid L. Even when the vicinity of circumferential edge of the wafer W is subjected to the exposure, the liquid L can be retained under the liquid contact surface 2a of the optical element 2 by the aid of the auxiliary plate 67.

[0025] FIG. 2 is a schematic diagram of a liquid-supplying-mechanism 10 in detail.

As shown in FIG. 2, the liquid-supplying-mechanism 10 for supplying predetermined liquid L onto the wafer W, includes: an ultra pure water device 11 for producing the liquid L; a thermostat reservoir 12 for controlling temperature of the liquid L; a pump 13 for flowing the liquid L; a pipe section 14 having sending-side-pipes 14a and returning-side-pipes 14b; a plurality of liquid-supplying-nozzles 15 disposed in the vicinity of the surface of the wafer W; and three-way valves 16 for controlling the quantity of liquid L supplied from the supply nozzles 15.

The ultra pure water device (refining device) 11, provided with: an ion-exchanging device 11a; a bactericidal-ultraviolet-ray (UV) lamp 11b; and a filtering device 11c, produces the liquid (water) L. The thermostat reservoir 12 controls temperature of the liquid L introduced from the ultra pure water device 11 to be ±0.01°C with respect to a predetermined temperature. The pump 13 supplies the liquid L, having the temperature controlled by the thermostat reservoir 12, to the pipe section 14 (sending-side-pipes 14a) so that the liquid L flows in the liquid-supplying-mechanism 10 entirely.

With respect to each sending-side-pipe 14a having two ends, one end thereof is connected to the pump 13, and the other end thereof is connected to the three-way valve 16; thus, the liquid L supplied from the pump 13 is introduced to the three-way valve 16. The returning-side-pipe 14b and the liquid-supplying-nozzle 15 are connected to each three-way valve 16 so that the liquid L introduced by the sending-side-pipe 14a is distributed into the returning-side-pipe 14b and the liquid-supplying-nozzle 15. The returning-side-pipe 14b is connected to the ultra pure water device 11 so that the liquid L which has not been supplied to the liquid-supplying-nozzle 15 is introduced to the ultra pure water device 11. Circulation flow paths in the liquid-supplying-mechanism 10 are formed by the above explained members: the ultra pure water device 11; the thermostat reservoir 12; the pump 13; the sending-side-pipes 14a; the three-way valves 16; and the returning-side-pipes 14b.

The liquid L supplied from the three-way valves 16 to the liquid-supplying-nozzles 15 is further supplied onto the wafer W by the liquid-supplying-nozzles 15. An open state of valve sections built in each three-way valve 16 is varied in accordance with command outputted from the control device CONT so that quantity of the liquid L supplied to the liquid-supplying-nozzles 15 is adjusted. By doing this, it is possible to: change the quantity of the liquid L supplied onto the wafer W in accordance with exposure sequences; or stop supplying the liquid L when the wafer W is exchanged.

With respect to each sending-side-pipe 14a, a temperature sensor 17, measuring the temperature of the liquid L which is about to be supplied onto the wafer W, is disposed therein near the three-way valve 16. Measurement results measured by the temperature sensor 17 are sent to the thermostat reservoir 12. The thermostat reservoir 12 controls the temperature of the liquid L in the thermostat reservoir 12 so that the temperature of the liquid L which is about to be supplied onto the wafer W is a predetermined temperature. With respect to each three-way valve 16, all the liquid L flowing in the sending-side-pipe 14a is made to flow in the returning-side-pipe 14b by the three-way valve 16; thus, the temperature of the flowing liquid L is measured by the temperature sensor 17 and adjusted by the thermostat reservoir 12. Therefore, it is possible to supply the liquid L having a predetermined and adjusted temperature onto the wafer W immediately after stopping the supply of the liquid L to the liquid-supplying-nozzle 15 and restarting the supply to the liquid-supplying-nozzle 15. In addition, with respect to the pipe sections 14, at least each sending-side-pipe 14a is surrounded by a thermally-insulating-member. By doing this, it is possible to adjust the temperature of the liquid L supplied onto the wafer W highly accurately.

[0026] FIGS. 3A and 3B show dispositions of: the liquid-supplying-nozzles 15 disposed in the liquid-supplying-mechanism 10; and liquid-collecting-nozzles 42 disposed in the liquid-collecting-mechanism 40. More specifically, FIG. 3A is a side view, and FIG. 3B shows a bottom end section of the projection optical system PL viewed from the wafer W.

With respect to directions defined on the surface of the wafer W, each liquid-supplying-nozzles 15 disposed in the vicinity of the surface of the wafer W is disposed differently with respect to each other. More specifically, as shown in FIG. 3B, four liquid-supplying-nozzles 15 are disposed around the liquid immersion region AR2 so that: one pair of the liquid-supplying-nozzles 15 are disposed on both sides (+X direction, -X direction) with respect to the scanning direction respectively; and another pair of the liquid-supplying-nozzles 15 are disposed on both sides (+Y direction, -Y direction) with respect to a non-scanning direction respectively.

Note that, members for flowing the liquid L therein and forming the liquid-supplying-mechanism 10 may be formed of a synthetic resin, e.g., polytetrafluorethylene. By doing this, impurities can be restricted in the liquid L. Thus, operation for supplying the liquid L by the liquid-supplying-mechanism 10 is controlled by the control device CONT, i.e., the control device CONT independently controls: the ultra pure water device 11; the thermostat reservoir 12; the pump 13; and the three-way valves 16. By doing this, it is possible to control: the quantity of liquid L produced by the liquid-supplying-mechanism 10; the temperature of the liquid L; and the quantity of liquid L supplied onto the wafer W per unit length of time, etc. (see FIG. 1).

[0027] With reference to FIG. 1 again, the liquid-col-

lecting-mechanism 40 collecting the liquid L disposed on the wafer W includes: a suction device 41 which can collect the liquid L; a plurality of the liquid-collecting-nozzles 42 disposed in the vicinity of the surface of the wafer W; and a connecting section 43 which connects the suction device 41 and the liquid-collecting-nozzles 42. The liquid-collecting-mechanism 40 further includes a tank, etc., for containing the collected liquid L, having been disposed on the wafer W, via the liquid-collecting-nozzles 42.

Similarly to the liquid-supplying-nozzles 15, with respect to directions defined on the surface of the wafer W, each liquid-collecting-nozzle 42 disposed in the vicinity of the surface of the wafer W is disposed differently with respect to each other. More specifically, as shown in FIG 3B, the liquid-supplying-nozzles 15 are disposed around the liquid immersion region AR2 so that: one pair of the liquid-supplying-nozzles 15 is disposed on both sides (+X direction, -X direction) with respect to the scanning direction respectively; another pair of the liquid-supplying-nozzles 15 is disposed on both sides (+Y direction, -Y direction) with respect to a non-scanning direction respectively; and each liquid-supplying-nozzle 15 is provided between by a pair of liquid-collecting-nozzles 42. This is intended: to prevent defects in the exposure device EX; and to prevent the liquid from leaking out of the liquid immersion region AR2, by disposing as many more sets of the liquid-collecting-nozzles 42 as possible than the liquid-supplying-nozzles 15.

Similarly to the liquid-supplying-mechanism 10, in order to restrict impurities included in the liquid L, members for flowing the liquid L therein and forming the liquid-collecting-mechanism 40 may be formed of a synthetic resin, e.g., polytetrafluorethylene.

Operation for collecting the liquid by the liquid-collecting-mechanism 40 is controlled by the control device CONT, i.e., it is possible to control the quantity of liquid L to-be-collected by the liquid-collecting-mechanism 40 per unit length of time.

[0028] Next, a method is explained for exposing images of the pattern PA of the reticle R onto the wafer W using the above explained exposure device EX.

To begin with, the reticle R is loaded onto the reticle stage RST, and the wafer W is loaded onto the wafer stage WST. In order to perform a scanning exposure process, the control device CONT: drives the liquid-supplying-mechanism 10; and starts supplying the liquid onto the wafer W.

With respect to operations for supplying the liquid, members included in the liquid-supplying-mechanism 10: the ultra pure water device 11; the thermostat reservoir 12; the pump 13; and the three-way valves 16, are operated; thus, the liquid L flows (circulates) in the circulation flow paths (pipe section 14). That is: the liquid L is produced by the ultra pure water device 11; the temperature of the liquid L is adjusted by the thermostat reservoir 12 based on measurement results outputted from the temperature sensor 17; and the pump 13 flows the liquid L at a predetermined flow rate. All the liquid L flows from the sending-side-pipes 14a to the returning-side-pipes 14b via the three-way valves 16. By doing this, the liquid L having highly accurately controlled temperature flows (circulates) in the circulation flow paths (pipe sections 14). Similarly to the previous refining operation, the liquid L flowing into the ultra pure water device 11 is refined through: the ion exchanging device 11a; the bactericidal-ultra-violet-ray (UV) lamp 11b; and the filtering device 11c; thus, impurities and bacterium included in the liquid L are eliminated. Similarly to the previous temperature control, the temperature of the liquid L is adjusted by the thermostat reservoir 12 again, and the temperature-adjusted liquid L is supplied to the sending-side-pipes 14a by the pump 13 again.

Next, the three-way valves 16 are operated so as to supply the liquid L from the liquid-supplying-nozzles 15 onto the wafer W.

By doing this, the liquid immersion region AR2 is formed under the liquid contact surface 2a of the optical element 2 disposed at a bottom end of the projection optical system PL. Note that not only all the liquid L flowing in the circulation flow paths (pipe sections 14) may be supplied to the liquid immersion area AR2 but also a portion of the liquid L flowing in the circulation flow paths (pipe sections 14) may be supplied to the liquid immersion area AR2. Fresh liquid L is produced by the ultra pure water device 11 so as to compensate for the portion supplied onto the wafer W and introduce the liquid L continuously into the sending-side-pipes 14a of the pipe section 14.

In addition, supplying the liquid L onto the wafer W from the liquid-supplying-nozzles 15 is maintained after forming the liquid immersion region AR2. Also, the liquid-collecting-mechanism 40 is operated simultaneously so as to: collect the liquid L in order to avoid flood of the liquid over the liquid immersion region AR2; and maintain such a state.

By doing this; the liquid immersion region AR2 is filled with the liquid L before starting the exposure; the temperature of the liquid is adjusted continuously; and the impurity-free-liquid is supplied and collected.

[0029] Next, predetermined preparations are conducted, e.g.: aligning the reticle R by using a reticle microscope and an off-axis alignment sensor, etc. (not shown in the drawings); and measuring base lines of alignment sensors, under the control by the control device CONT after setting various exposure conditions. After that, fine alignment (enhanced global alignment (EGA), etc.) of the wafer W using the alignment sensors is completed; thus, disposition coordinates with respect to a plurality of shot regions on the wafer W are determined.

After completing the preparation for exposing the wafer W, the control device CONT, while monitoring values measured by the laser interferometer 66, drives the wafer stage driving section 61 to an acceleration starting position (scanning start position) for a first exposure shot (first shot region) to the wafer W and moves the wafer stage WST in accordance with results obtained in the alignment sensing operation.

Next, the control device CONT: drives the reticle stage driving section 51 and the wafer stage driving section 61; and starts scanning the reticle stage RST and the wafer stage WST with respect to the X axis direction. After the reticle stage RST and the wafer stage WST reach a predetermined scanning speed respectively, the pattern regions of the reticle R are illuminated by the exposure light beam EL emitted from the illuminating optical system IL, and the scanning exposure begins.

Different sections in the pattern region of the reticle R are illuminated by the exposure light beam EL sequentially. By completing the illumination on all the pattern regions, the scanning exposure for the first shot region on the wafer W is completed. By doing this, a reduced-size pattern PA of the reticle R is transferred onto a photo-resist layer in the first shot region on the wafer W via the projection optical system PL and the liquid L.

After the scanning exposure to the first shot region is completed, the control device CONT moves the wafer stage WST with respect to the X axis direction and the Y axis direction stepwise to be at the acceleration starting position for exposing a second shot region. That is, an inter-shot stepping movement is conducted.

The above explained scanning exposure is conducted on the second shot region.

By doing this, the scanning exposure to the shot regions on the wafer W and the stepping movements for exposing the following shot regions are repeated; thus, the pattern PA of the reticle R is transferred onto all the shot regions-to-be-exposed on the wafer W sequentially.

Also, when the wafer W is exposed, the control device CONT adjusts the open state of the three-way valves 16 in accordance with a target scanning speed so that a necessary quantity of the liquid L in accordance with the target scanning speed is supplied onto the wafer W. An appropriate one of the three-way valves 16 is selected in accordance with the scanning direction and the stepping direction of the wafer W; thus, opening/closing movement is conducted by the selected three-way valve 16.

[0030] After exposing the wafer W, the three-way valves 16 disposed in the liquid-supplying-mechanism 10 are operated so as to stop supplying the liquid L onto the wafer W. In addition, operation of the ultra pure water device 11, the thermostat reservoir 12, and the pump 13 is maintained. Therefore, the liquid L in the liquid-supplying-mechanism 10 keeps flowing (circulating) in the above explained circulation flow paths (pipe sections 14). Also, the liquid-collecting-mechanism 40 is operated so as to collect all the liquid L disposed on the liquid immersion region AR2.

After completing collecting the liquid L, the wafer W is exchanged so as to form the liquid immersion region AR2 on a new wafer W; and the exposure is started.

By repeating such operations, a plurality of wafers W are exposed.

[0031] As above explained, when the wafer W is exchanged, the liquid-supplying-mechanism 10 stops supplying the liquid L onto the wafer W. Therefore, as far as the liquid-supplying-mechanism in a conventional exposure apparatus is concerned, liquid L stops in pipes disposed between the thermostat reservoir and liquid-supplying-nozzles. Such unmoving liquid L may be affected by external factors, i.e.: temperature of the liquid L may vary; impurities are included in the liquid L; and bacterium grow in the liquid L. In particular, if the liquid-supplying-mechanism 10 stops supplying the liquid onto the wafer W for a long time for purposes, e.g., repair, and inspection, the temperature of the unmoving liquid L inevitably varies.

Therefore, in the conventional exposure apparatus, it is necessary to discharge the stopped liquid L in the pipes disposed between the thermostat reservoir and the liquid-supplying-nozzles if the liquid-supplying-mechanism 10 stops supplying the liquid L onto the wafer W and restarts supplying the liquid L again so as to form the liquid immersion region AR2 on a new wafer W. If the liquid L is highly contaminated, time necessary for such disposal will be too long; thus, non-working time of the exposure apparatus will be prolonged.

[0032] However, as far as the exposure apparatus of the present invention is concerned, the liquid L in the liquid-supplying-mechanism 10 flows, i.e., circulates continuously even when the liquid-supplying-mechanism 10 stops supplying the liquid L onto the wafer W. In addition, the ultra pure water device 11 and the thermostat reservoir 12 are disposed on the circulation flow paths. Therefore, the liquid L is refined through members of the ultra pure water device 11, i.e.: ion exchanging device 11a; the bactericidal-ultra-violet-ray (UV) lamp 11b; and a filtering device 11c. Impurities and bacterium included in the liquid L are eliminated accordingly. In addition, the liquid L passes through the thermostat reservoir 12 several times; thus, the temperature of the liquid L can be adjusted uniformly.

By doing this, according to the exposure apparatus EX of the present embodiment, the temperature of the liquid L is prevented from varying and contamination is prevented even if the liquid-supplying-mechanism 10 stops supplying the liquid L onto the wafer W. Therefore, it is possible to form the liquid immersion region AR2 and restart the exposure immediately after exchanging the wafer without discharging the contaminated liquid L.

[0033] As explained above, it is possible to continuously fill the temperature-controlled liquid L under the liquid contact surface 2a of the optical element 2 disposed in a bottom end of the projection optical system PL in the present embodiment of the exposure apparatus EX. In addition, the liquid L is ultra pure water; thus, there is an advantage that a photo-resist and the optical elements disposed on the wafer W are not affected. Also, ultra pure water does not affect ambient conditions and contains an extremely low amount of impurities; therefore, function, i.e., effect can by expected for cleaning the liquid contact surface 2a of the optical element 2 by the ultra pure water. Refractive index n of ultra pure water (water)

with respect to the exposure light beam EL having a wavelength of 193 nm is approximately 1.47; therefore, if a light source for emitting the exposure light beam EL emits an ArF excimer laser beam (having wavelength 193 nm), high resolution having approximately 131 nm of shortened, i.e., 1/n, wavelength can be obtained on the wafer W. The depth of focus is magnified by approximately by 1.47 times, i.e., magnified n times than a case in which air exists instead of the liquid immersion region AR2. Therefore, a greater numerical aperture of the projection optical system PL can be realized than in the case in which air exists instead of the liquid immersion region AR2 as long as the depth of focus remains equivalent whether air or liquid is used. This insight improves the obtained resolution.

[0034] FIG. 4 is a schematic view showing the liquid-supplying-mechanism 30 in which a part of pipe sections are formed by double pipes. Same reference numerals are added to the same members as the liquid-supplying-mechanism 10 so as to omit explanations thereof.

As shown in FIG. 4, a part of a pipe section 32 in a liquid-supplying-mechanism 30 is a double pipe formed by inner pipes 32a and outer pipes 32b.

Thus, circulation flow paths of the liquid L produced by the ultra pure water device 11 are formed by: flow paths (sending-side-paths) formed by introducing the liquid L into the inner pipes 32a of the pipe section 32 via the thermostat reservoir 12 and the pump 13, and by leading to tip sections of the pipe section 32; and flow paths (returning-side-paths) formed from tip sections of the pipe section 32 to the ultra pure water device 11 through the outer pipes 32b forming the pipe section 32.

Also, the liquid-supplying-nozzle 15 is disposed on a tip of each pipe section 32 via a control valve (two-way valve) 34 so that at least a portion of the liquid L flowing in the circulation flow paths (pipe sections 32) is discharged (supplied) onto the wafer W from the liquid-supplying-nozzles 15 by releasing the control valve 34.

In the liquid-supplying-mechanism 30 according to the present embodiment, a part of each piping section is a double pipe having the inner pipe 32a and the outer pipe 32b. In addition, the liquid L flows in the circulation flow paths, which is composed of the inner pipe 32a acts as a sending-side-path and the outer pipe 32b acts as a returning-side-path. Therefore, the liquid L flowing in the outer pipe 32b serves as a thermally-insulating-material; thus, it is possible to restrict the temperature of the liquid L from varying. In particular, because of the flowing liquid L serving as the thermally-insulating-material, the thermal-insulating effect is high. In addition, it is possible to obtain a more desirable thermal-insulating effect by using the liquid L, i.e. water having a greater specific heat. It is desirable e.g., to wind the thermally-insulating-material around a non-double-pipe portion of the pipe sections 32. By doing this, it is possible to: supply the refined and temperature-controlled liquid L onto the wafer W stably; restrict the wavelength of the exposure light beam EL emitted onto the liquid immersion region AR2 from varying; and expose micro-patterns PA onto the wafer W.

FIG. 5 is a schematic view showing an embodiment of a liquid-supplying-mechanism 70 different from the liquid-supplying-mechanism 30. Same reference numerals are added to the same members of the liquid-supplying-mechanism 30 so as to omit explanations thereof.

The liquid-supplying-mechanism 70 is different from the liquid-supplying-mechanism 30 in that a second temperature sensor 18 is disposed on each liquid-supplying-nozzle 15 in the liquid-supplying-mechanism 70. Each second temperature sensor 18 measures the temperature of the liquid L which has passed the control valve 34 and is about to be supplied onto the wafer W. Measurement results measured by each second temperature sensor 18 are sent to the thermostat reservoir 12. The thermostat reservoir 12 controls the temperature of the liquid L contained in the thermostat reservoir 12 in accordance with a measurement result corresponding to at least one of the temperature sensor 17 and the temperature sensor 18.

Controlling the temperature of the liquid L in the present embodiment is explained in detail. To begin with, each control valve 34 is released. If at least a portion of the liquid L flowing in the inner pipes 32a is supplied onto the wafer W, the thermostat reservoir 12 controls the temperature of the liquid L so that the measurement results measured by the second temperature sensor 18 coincide with a predetermined target temperature. Simultaneously, the measurement result measured by each first temperature sensor 17 is memorized. Alternatively, the difference between the measurement result measured by the second temperature sensor 18 and the measurement result measured by the first temperature sensor 17 may be memorized.

Next, each control valve 34 is closed so as to stop supplying the liquid L onto the wafer W. If all of the liquid L flowing in the inner pipes 32a flows into the outer pipes 32b, the liquid L does not pass through each liquid-supp-plyng-nozzle 15. The measurement results measured by the second temperature sensors 18 are not suitable for controlling the temperature of the liquid L because each second temperature sensor 18 cannot measure the temperature of the flowing liquid L. Therefore, with respect to the thermostat reservoir 12, temperature sensors used for controlling the temperature of the liquid L are switched to the first temperature sensors 17 so that the temperature of the liquid L is controlled to be the predetermined target temperature using only the first temperature sensors 17. In this case, the thermostat reservoir 12 uses the temperature which is measured by the first temperature sensors 17 in a state where the control valves 34 are released; and the temperature of the liquid L is controlled using the second temperature sensors 18 as the target temperature. Alternatively, the previously-memorized value, i.e., difference between the measurement result obtained by the second temperature sensor 18 and the measurement result obtained by the (first) temperature sensor 17, may be offset to the final target temper-

ature of the liquid L so as to determine the current target temperature of the liquid L.

The liquid-supplying-mechanism 70 of the present embodiment is provided with the second temperature sensors 18; therefore, it is possible to measure the temperature of the liquid L which has passed the control valves 34, and it is possible to control the temperature of the liquid L supplied onto the wafer W more reliably. Also, the liquid-supplying-mechanism 70 has several pairs of temperature sensors, i.e., several pairs of the first temperature sensor 17 and the second temperature sensor 18, so that each control valve 34 is provided between each pair of the sensors. Therefore, it is possible to maintain optimum temperature of the liquid L even if the control valves 34 are closed. As a result of this, it is possible to control the temperature of the liquid L to be the target temperature whenever the control valves 34 are released afterwards.

[0035] The sequence of operations explained in the above embodiment, shapes of members used in the embodiment, and combination thereof are mere examples. Various modifications are possible within the scope and spirit of the present invention in accordance with other factors, e.g., processing conditions and design requirements, etc. The present invention includes the following modifications.

[0036] The present invention is not limited to the above explained embodiment showing an example in which the liquid L, flowing in the returning-side-pipes (outer pipes) 14b and 32b of the pipe sections 14 and 32, returns to the ultra pure water device 11. That is, the liquid L which has not been supplied onto the wafer W may be discharged: to the liquid-collecting-mechanism 40; or out of the exposure apparatus EX.

Also, with respect to the liquid-supplying-mechanisms 10 and 30, the liquid L which has not been supplied onto the wafer W may be returned to the thermostat reservoir 12 instead of the ultra pure water device 11.

In order to return the liquid L to the thermostat reservoir 12, it is desirable to dispose filters and disinfecting devices between: the returning-side-pipes (outer pipes) 14b and 32b in the pipe sections 14 and 32; and; the thermostat reservoir 12.

The liquid L which has not been supplied onto the wafer W may be returned to the ultra pure water device 11 and the thermostat reservoir 12 while discharging a predetermined quantity of the liquid L: to the liquid-collecting-mechanism 40; or out of the exposure apparatus EX.

The present invention is not limited to the above explained embodiment showing an example in which the exposure apparatus EX has the ultra pure water device 11. That is, ultra pure water (liquid L) may be supplied to the exposure apparatus EX from the semiconductor factory. In such a case, the liquid L flowing in the returning-side-pipes 14b (outer pipes 32b) may be returned to the ultra pure water device 11. In addition, the flow of the liquid L in the returning-side-pipes 14b (outer pipes 32b) may be joined to the liquid-collecting-mechanism 40. Also, the liquid L may be exhausted out of the exposure apparatus EX.

The present invention is not limited to the above explained embodiment in which the temperature of the liquid L is adjusted only using the thermostat reservoir 12. That is, additional temperature-controlling-devices may be disposed in the vicinity of the liquid-supplying-nozzles 15. In such a case, the temperature-controlling-devices may be formed by combining: heaters; peltier elements; the liquid-supplying-nozzles 15; and temperature sensors.

[0037] Also, as shown in FIGS. 3A and 3B, the liquid-supplying-nozzles 15 and the liquid-collecting-nozzles 42 may have various shapes, e.g., taper, fan, and slit. Also, with respect to dispositions and quantities, various modifications are possible to the liquid-supplying-nozzles 15 and the liquid-collecting-nozzles 42 desirably.

[0038] In the above explained embodiment, the optical element 2, attached to a tip of the projection optical system PL, is a lens. It is possible to adjust optical characteristics, i.e., aberrations, e.g., spherical aberration and comatic aberration by the lens. With respect to a cheaper material than the lens, a plate having parallel plain surfaces can be used for the optical element 2.

Compared to the optical element, i.e., lens contacting the liquid L, it is advantageous to use a plate having parallel and plane surfaces from a cost point of view because replacing a plate having parallel plain surfaces with another new plate having parallel plain surfaces can be conducted adjacent to supplying the liquid L even if substances (e.g., silicon-containing organic substance) deteriorating optical characteristics, i.e., transmissivity with respect to the projection optical system PL, illumination intensity on the wafer W illuminated by the exposure light beam EL, and illumination distribution uniformity thereon attach to the plate during: transporting; assembling; and adjusting the exposure apparatus EX. That is, the surfaces of the optical element contacting the liquid L may be stained if particles, splashing from photo-resist illuminated by the exposure light beam EL or impurities included in the liquid L, attach thereto. Therefore, the optical element must be replaced periodically. Replacing such an optical element with a plate having parallel and plain surfaces can realize: a lower cost of replacement parts than the lens; and shorter time for exchanging a plate with another. Thus, it is possible to restrict: increase in maintenance cost (running cost); and decrease in throughput.

[0039] Also, with respect to a pressure value indicating a pressure difference caused by the flow of the liquid L, if there is a great difference between the optical element 2 disposed at the tip of the projection optical system PL and the wafer W, the optical element 2 may be fixed thereon so as not to be affected by the pressure difference instead of using an exchangeable optical element 2.

[0040] Although water is used as the Liquid L in the above explained embodiment, the liquid L may be other than water. For example, considering that one of the ex-

posure light beams EL, i.e., F_2 laser, is not transmissive through water, the liquid L may be a fluorine fluid, e.g., a fluorocarbon oil or a perfluoropolyether (PFPE) fluorocarbon fluid through which the F_2 laser is transmissive. In such a case, it is desirable that liquid affinity is imparted to a part of the optical element contacting the liquid L by forming thin films thereon including molecular substances having small polarity, e.g., fluorine.

Also, another liquid can be used, e.g., cedar oil having: transmittance with respect to the exposure light beam EL; as high a refractive index as possible; and stability with respect to the photo-resist coated on the projection optical system PL and the surface of the wafer W. In such a case, surface treatment is conducted in accordance with the polarity of the liquid L.

[0041] Also, the wafer W is not limited to semiconductor wafers used for manufacturing semiconductor devices. That is, glass substrates used for display devices, and ceramic wafers used for thin-film magnetic heads are available for use.

[0042] The exposure apparatus EX may be: not only a scanning exposure device (scanning stepper) which uses a step-and-scan method in which a pattern of the reticle is scanned and exposed by moving the reticle and the wafer synchronously; but also a projection exposure device (stepper) which uses a step-and-repeat method in which the pattern of the reticle is exposed in a single exposure session while the reticle and the wafer being substantially kept stationarily, and the wafer is moved in a step manner. Also, the present invention can be applied to an exposure device which uses a step-and-stitch method in which at least two partially-overlapping patterns are transferred onto the wafer.

[0043] Also, the present invention can be adapted to twin-stage exposure apparatuses disclosed in, e.g.: Japanese Unexamined Patent Application, First Publication No. H 10-163099; Japanese Unexamined Patent Application, First Publication No. H 10-214783; and Published Japanese translation No. 2000-505958.

[0044] Types of the exposure apparatus EX are not limited to exposure devices used to manufacture semiconductor elements by exposing patterns of semiconductor elements onto wafers. The exposure apparatus EX may be a wide variety of exposure devices used to manufacture, e.g., liquid crystal display elements, displays, thin-film magnetic heads, image-capturing elements (CCD), reticles, or masks.

[0045] Linear motors in accordance with any one of types, e.g., an air-floating linear motor which uses air-bearings, and a magnetic-levitation-type linear motor which uses Lorentz force or reactance force, can be used for the wafer stage and the reticle stage. Also, the stages in accordance with any one of types, e.g., moving along guides, and moving without guides, can be used. In addition, flat motors can be used for a device for driving stages by: connecting one of either a magnetic unit (permanent magnet) or an armature unit to the stage; and disposing the other one of either the magnet unit or the armature unit onto a moving-side of stage (base).

[0046] The reaction force generated by the movement of the wafer stage may be released to a floor (ground) mechanically, e.g., using frame members as disclosed in Japanese Unexamined Patent Application, First Publication No. H 8-166475.

[0047] The reaction force generated by the movement of the reticle stage may be released to a floor (ground) mechanically, e.g., using frame members as disclosed in Japanese Unexamined Patent Application, First Publication No. H 8-330224.

[0048] The numerical aperture (NA) with respect to the projection optical system may be 0.9 to 1.3 in the case of the liquid immersion method as explained above. The image-focusing capability of the projection optical system having such a large numerical aperture NA may be deteriorated due to a polarization effect if conventional exposure light beam, e.g., a random-polarization light beam is used. Therefore, it is desirable to use polarization illumination. In such a case, it is desirable to illuminate beams having linear polarizations corresponding to a longitudinal direction with respect to line patterns forming a line-and-space pattern on the reticle so that more diffracted beams having S-polarization component (polarization component corresponding to a longitudinal direction with respect to the line pattern) are emitted from the reticle pattern. Compared to a case in which a space between: a photo-resist coating a surface of a wafer; and the projection optical system, is filled by air (gaseous substance), transmissivity of diffracted beams having S-polarization component, which contribute to improving contrast, is high on a surface of the photo-resist if the space between: the photo-resist coating the surface of wafer; and the projection optical system, is filled by liquid. Therefore, it is possible to realize better image-focusing capability even if the numerical aperture NA of the projection optical system exceeds 1.0. Also, it is more effective to combine a phase-shift mask and oblique incident illumination method (in particular, dipole-illumination-method) conducted corresponding to a longitudinal direction with respect to the line pattern disclosed in, e.g., Japanese Unexamined Patent Application, First Publication No. H 6-188169.

Also, it is effective not only to combine: the oblique incident illumination method; and a linear polarization illumination (S-mode polarization illumination) method in which beams correspond to a longitudinal direction of the line pattern of the reticle; but also to combine: the oblique incident illumination method; and a polarization illumination method in which beams have linear polarization (modes) with respect to a tangent line direction contacting a circle having a center corresponding to an optical axis, as disclosed in Japanese Unexamined Patent Application, First Publication No. H 6-53120. In particular, even if: the numerical aperture NA of the projection optical system is remarkably great; and the reticle pattern includes not only line patterns expanding with respect to a predetermined direction but also line patterns expand-

ing with respect to a plurality of different directions, it is possible to realize better image-focusing capability by compatibly conducting: the polarization illumination method in which beams have linear polarization (modes) with respect to a tangent line direction contacting a circle having a center corresponding to an optical axis; and annular illumination method; as disclosed in the previously mentioned Japanese Unexamined Patent Application, First Publications No. H 6-53120.

[0049] The exposure apparatus adapting the present invention is manufactured by assembling various sub-systems, e.g., each element recited in Claims of the present application so that the exposure device maintains predetermined accuracies, i.e., mechanical accuracy, electrical accuracy, and optical accuracy. In order to achieve these accuracies, the optical accuracy is adjusted in each of the optical systems, the mechanical accuracy is adjusted in each of the mechanical systems, and the electrical accuracy is adjusted in each of electrical systems before and after the assembly. Steps in which the sub-systems are assembled to manufacture the exposure device include mutual connections, i.e., mechanical connection among the sub-systems, electrical connection of wirings and electrical circuits, and pipe connection of air pressure circuits. Each one of the sub-systems must be assembled before the assembly of the sub-systems to manufacture the exposure device. After assembling the sub-systems to manufacture the exposure device is completed, comprehensive adjustment is conducted; thus, the accuracies are obtained for the entire exposure device. It is desirable that the exposure device be manufactured in clean rooms in which temperature and cleanliness are controlled.

[0050] Also, as shown in FIG. 6, the semiconductor device is manufactured by: step 201 for designing function and capability of the device; step 202 for manufacturing a mask (reticle) based on the design of the step 201; step 203 for manufacturing wafers from a silicon material; step 204 for treating the wafers, step 204 including a photolithographic step in which patterns of the reticle are exposed onto the wafers using the exposure apparatus of the above explained embodiment; step 205 for assembling devices, e.g., dicing step, bonding step, and packaging step; and step 206 for inspection, etc.

INDUSTRIAL APPLICABILITY

[0051] According to the present invention, the liquid does not stop in the pipe sections when wafers are exchanged; therefore, the temperature of the liquid hardly varies and contaminants hardly invade into the liquid. Also, it is possible to prevent: the temperature of the liquid from varying; and the liquid from containing impurities, while minimizing the quantity of the liquid-to-be-consumed. Also, it is possible to supply the liquid having an approximately constant temperature onto the substrate from the liquid-supplying-section.

Claims

1. An exposure apparatus that: projects pattern images onto a substrate via a liquid and a projection optical system, the liquid forming a liquid immersion region between the projection optical system and the substrate; and exposes the substrate, the apparatus comprising:

   a liquid-supplying-section that supplies the liquid onto the substrate;
   a first pipe section that introduces the liquid to the liquid-supplying-section; and
   a second pipe section, connected to the first pipe section, that collects the liquid which has not been supplied to the liquid-supplying-section from the first pipe section.

2. An exposure apparatus according to Claim 1, wherein at least a portion of the liquid circulates in the first pipe section and the second pipe section.

3. An exposure apparatus according to Claim 1, further comprising a thermostat reservoir which: maintains the temperature of the liquid approximately constant; and supplies the liquid to the first pipe section.

4. An exposure apparatus according to Claim 3, further comprising temperature measuring sections that measure the temperature of the liquid supplied onto the substrate, the temperature control sections being disposed at least in one of the first pipe section and the liquid-supplying-section, wherein
   the thermostat reservoir controls the temperature of the liquid in accordance with measurement results measured by the temperature measuring sections.

5. An exposure apparatus according to Claim 3, wherein the second pipe section is connected to the thermostat reservoir.

6. An exposure apparatus according to Claim 1, further comprising a refining device that refines the liquid supplied to the first pipe section.

7. An exposure apparatus according to Claim 6, wherein the second pipe section is connected to the refining device.

8. An exposure apparatus according to Claim 1, wherein the first pipe section and the second pipe section form a double pipe so that the second pipe section is disposed around the first pipe section together.

9. An exposure apparatus according to Claim 1, wherein the liquid-supplying-section has an aperture mechanism that adjusts a quantity of the liquid supplied onto the substrate.

10. An exposure apparatus according to Claim 1, wherein the first pipe section, the second pipe section, and the liquid-supplying-section, are connected by three-way-valves.

11. An exposure method of: forming a liquid immersion region by supplying liquid between a projection optical system and a substrate; projecting pattern images onto the substrate via the liquid and the projection optical system; and exposing the substrate, the method comprising:

flowing the liquid; and
supplying at least a portion of the flowing liquid to the substrate.

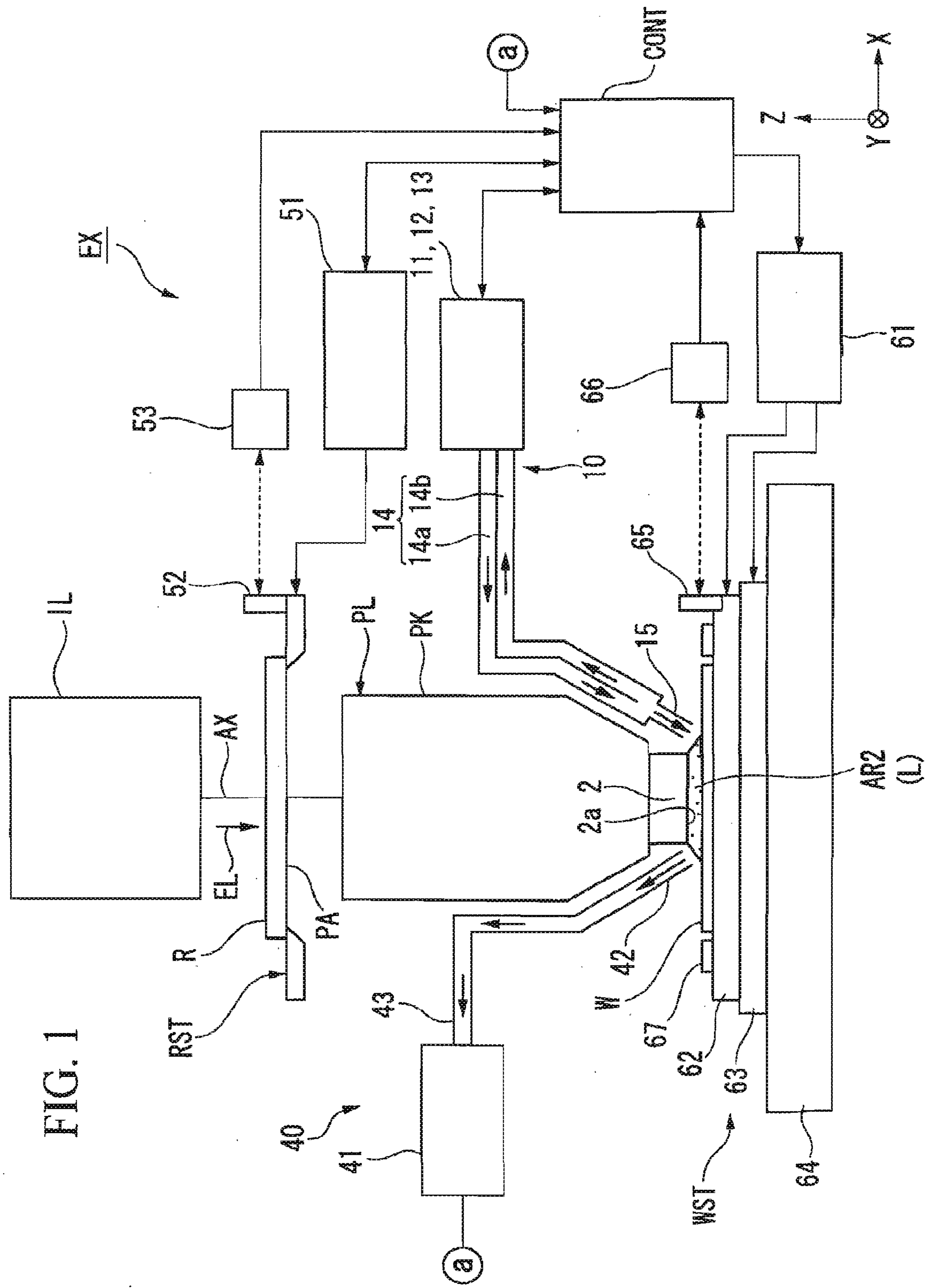
12. An exposure method according to Claim 11, further comprising:

stopping supplying the liquid onto the substrate; and
flowing all the liquid.

13. An exposure method according to Claim 11, further comprising:

collecting the liquid;
controlling temperature of the collected liquid; and
supplying the temperature-controlled liquid.

14. A device-manufacturing method including lithographic steps, wherein the method uses the exposure apparatus according to any one of Claims 1 to 10.


EX
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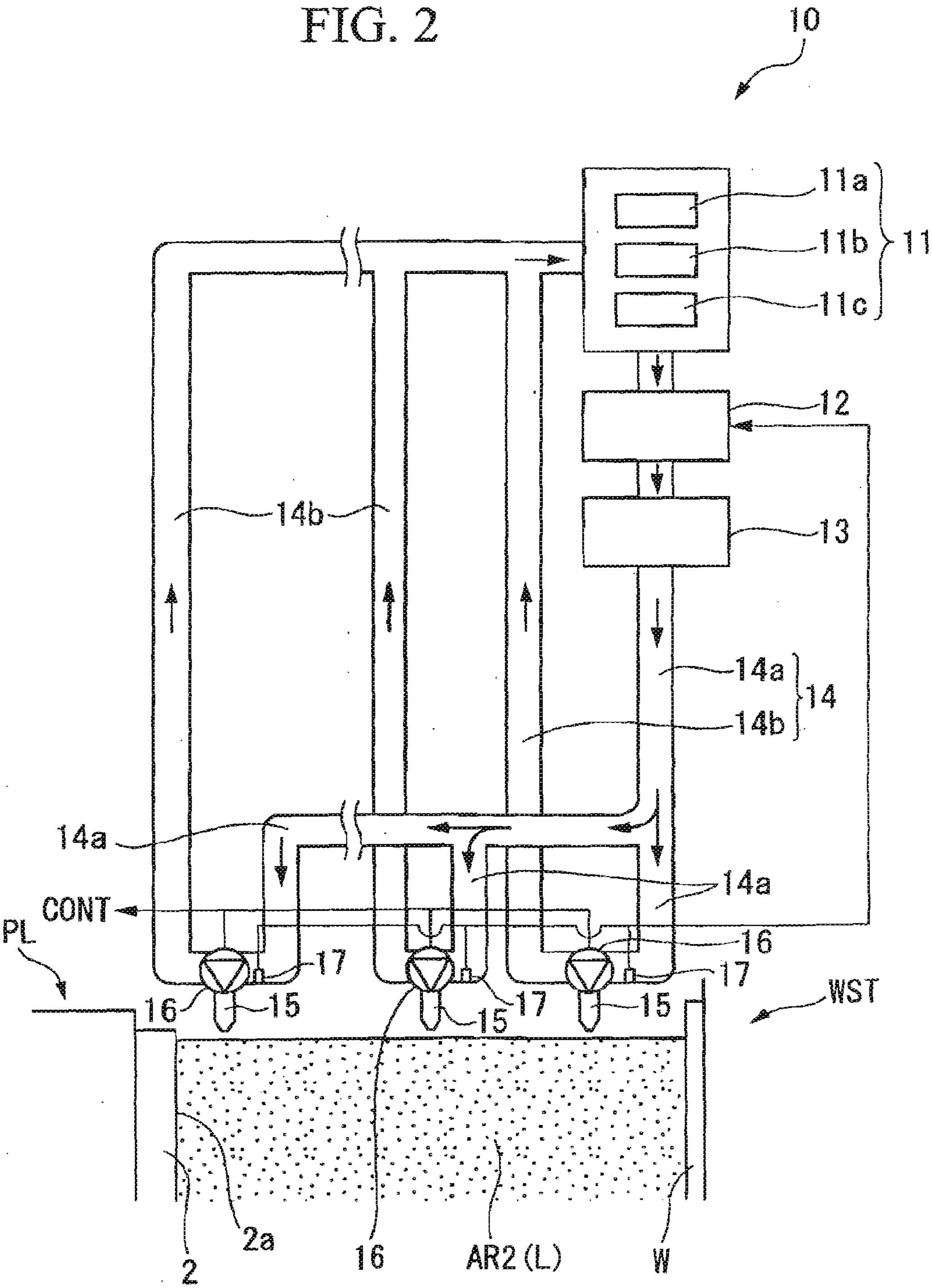
AX
EL
R
RST
PA
PL
PK
52
53
51
11, 12, 13
10
14
14a
14b
15
CONT
a
Z
Y
X
66
65
61
2a
2
AR2
(L)
42
43
40
41
a
W
67
62
63
WST
64

FIG. 1

FIG. 2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11a
11b
11
11c
12
13
14b
14a
14
14b
14a
14a
CONT
16
PL
17
17
16
15
15
17
15
WST
2a
2
16
AR2 (L)
W

FIG. 3A

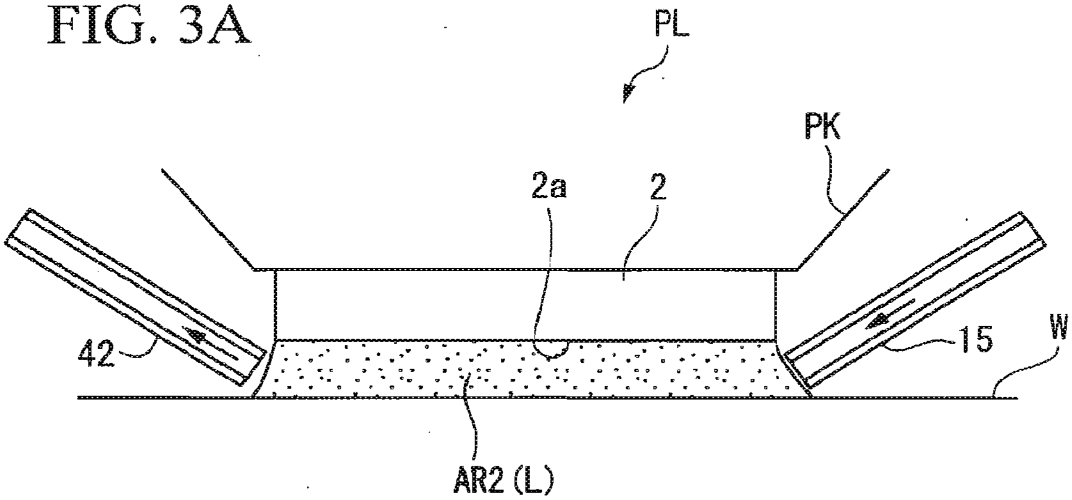


FIG. 3B

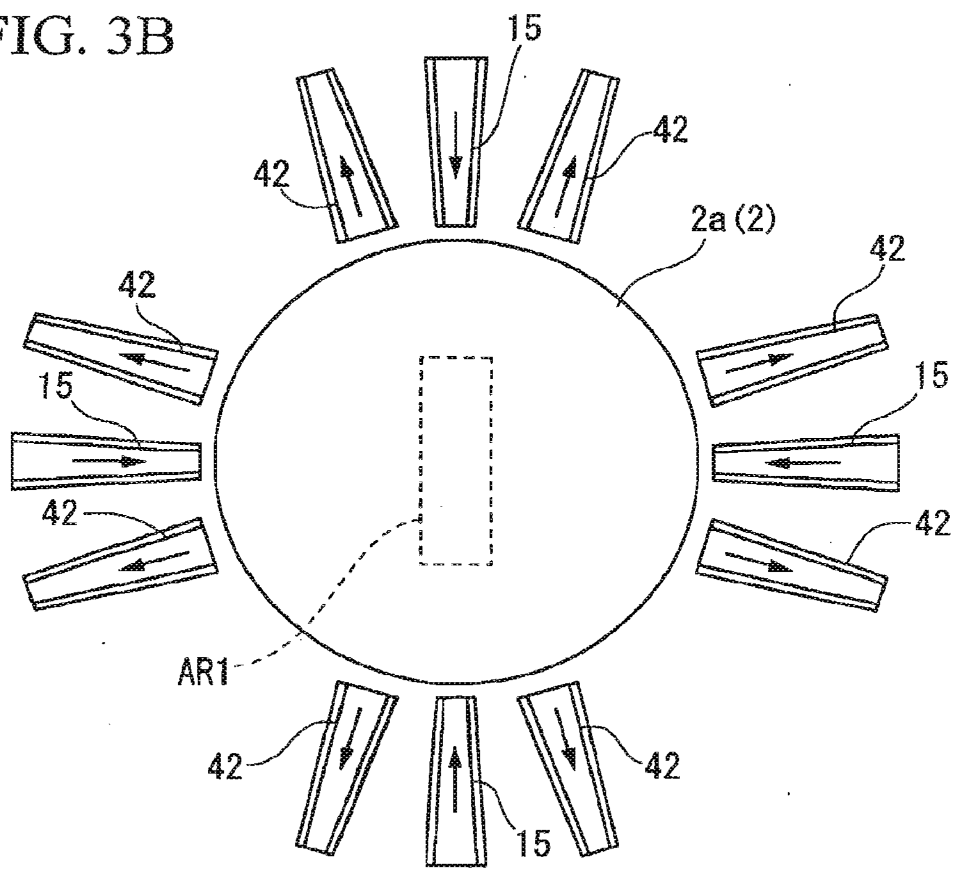


FIG. 4

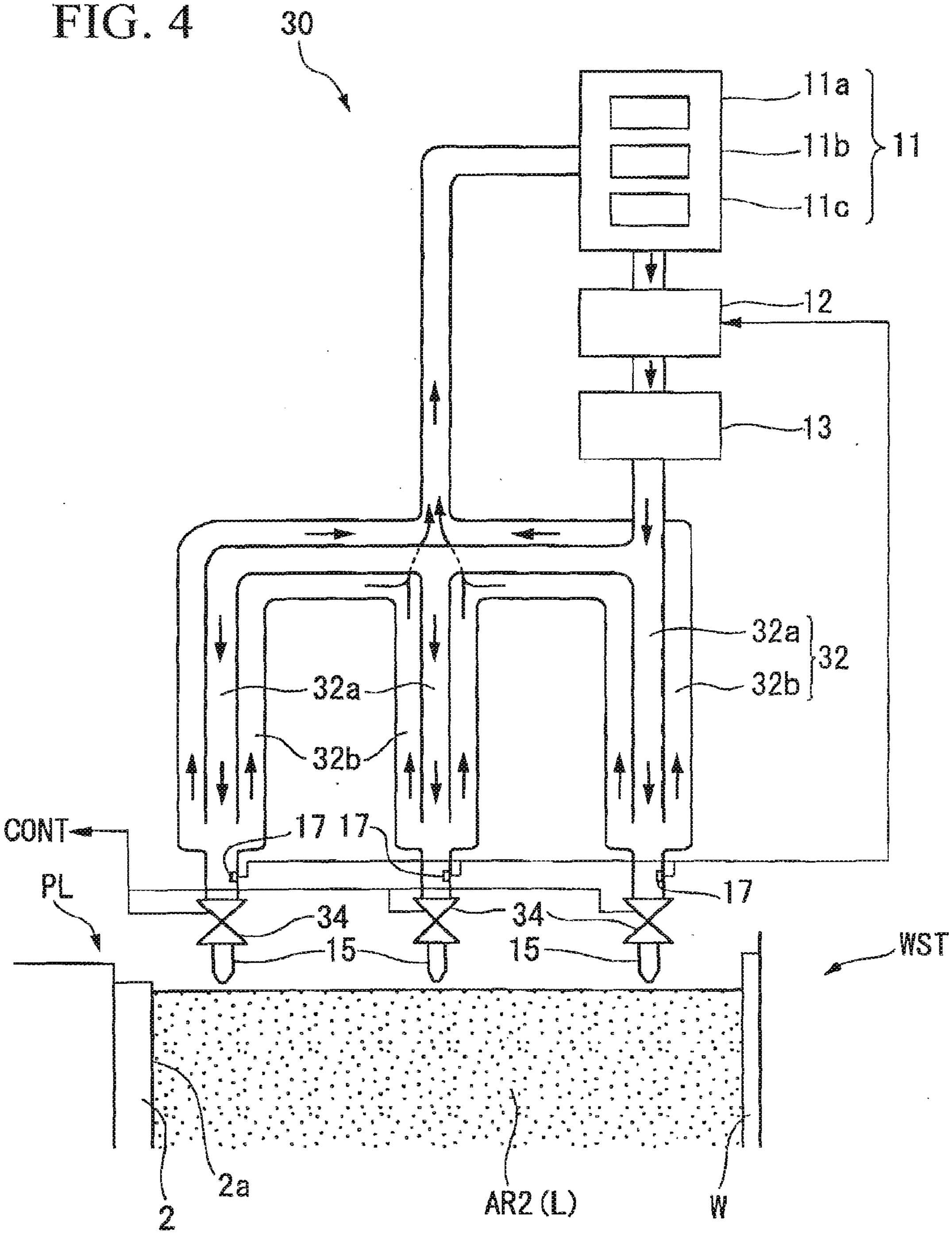
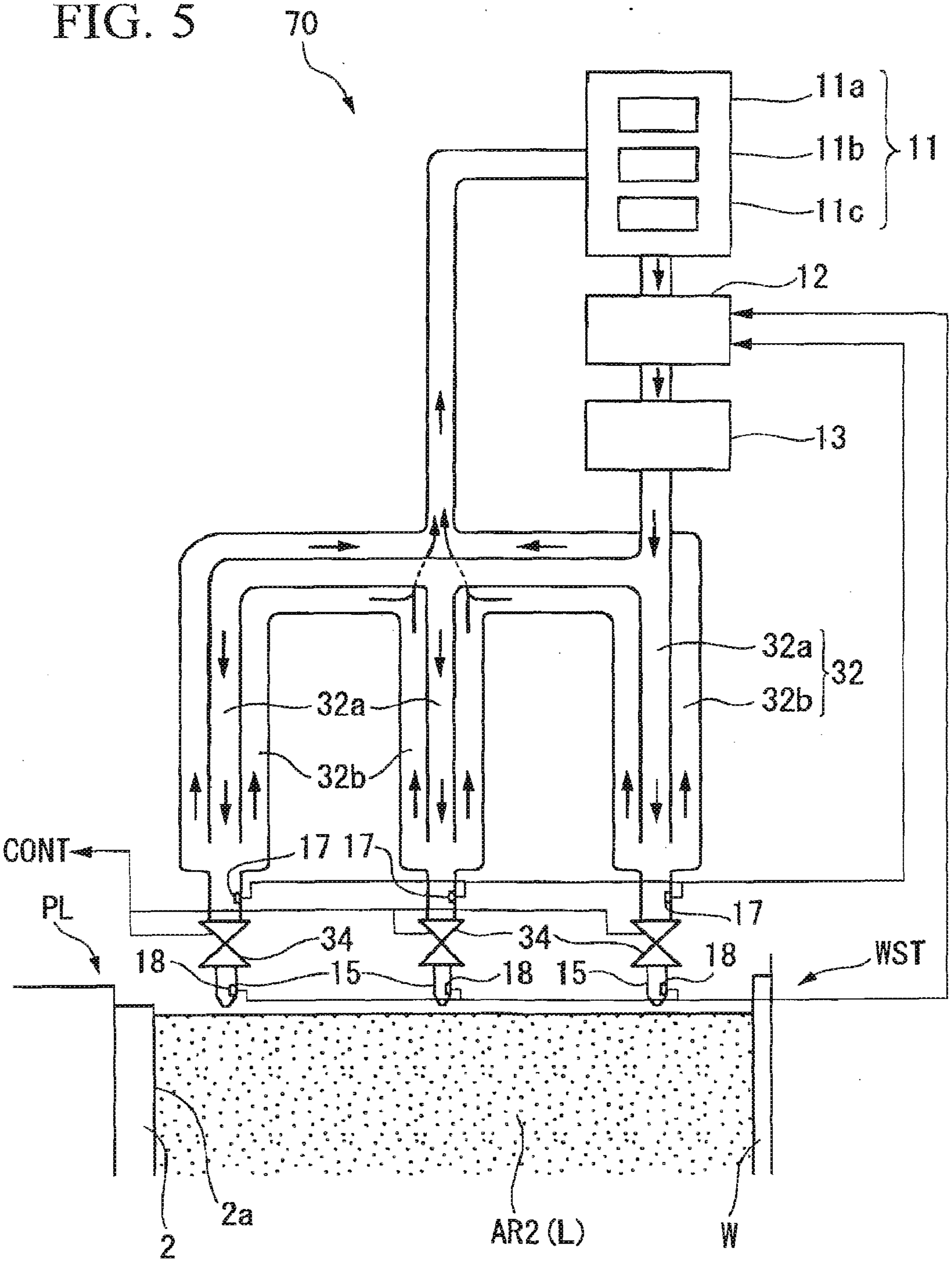

30
11a
11b
11c
11
12
13
32a
32
32b
32a
32b
CONT
17 17
17
34
34
15
15
PL
WST
2a
2
AR2 (L)
W

FIG. 5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11a
11b
11
11c
12
13
32a
32
32b
32a
32b
CONT
17 17
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PL
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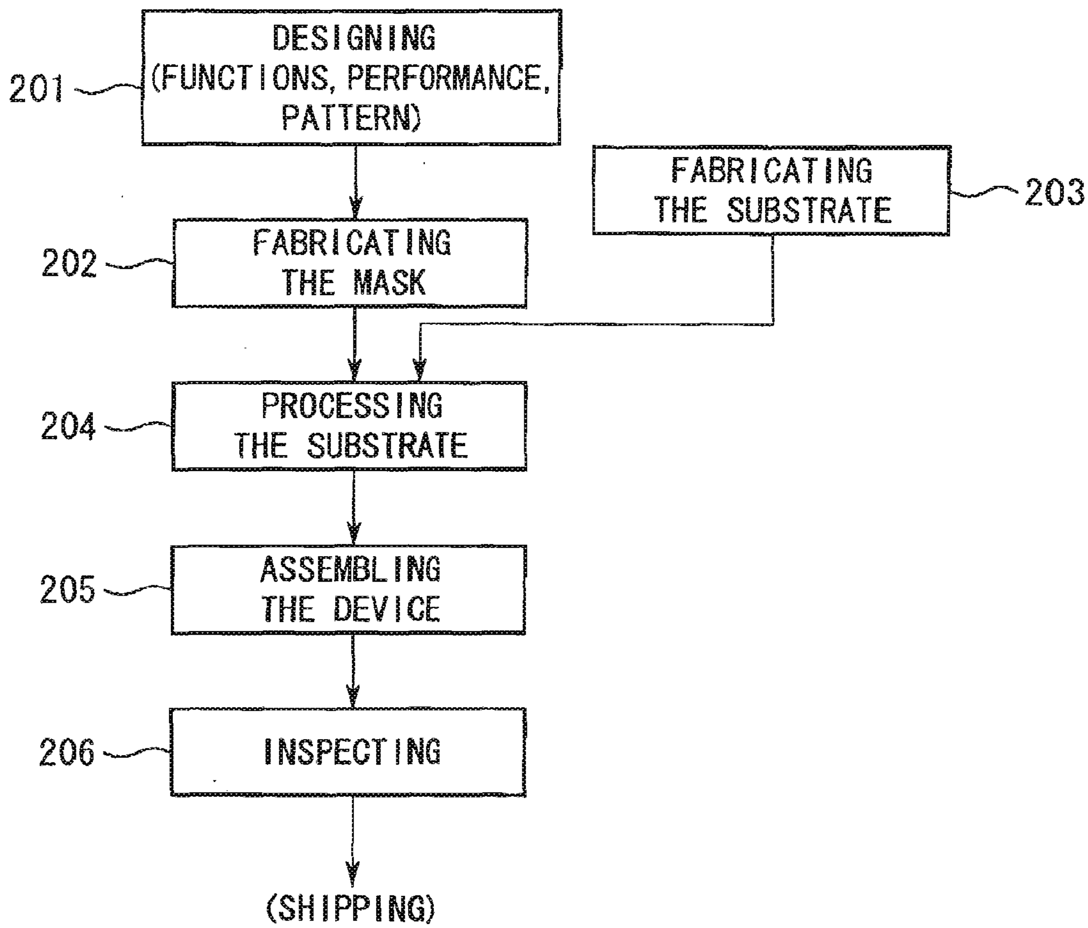
15
18
15
18
WST
2a
2
AR2 (L)
W

FIG. 6


DESIGNING
(FUNCTIONS, PERFORMANCE,
PATTERN)
201
FABRICATING
THE SUBSTRATE
203
FABRICATING
THE MASK
202
PROCESSING
THE SUBSTRATE
204
ASSEMBLING
THE DEVICE
205
INSPECTING
206
(SHIPPING)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2004/015619

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According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
Int.Cl^{7} H01L21/027, G03F7/20, G02B7/02

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho	1922-1996	Toroku Jitsuyo Shinan Koho	1994-2004
Kokai Jitsuyo Shinan Koho	1971-2004	Jitsuyo Shinan Toroku Koho	1996-2004

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A X	WO 99/49504 A (Nikon Corp.), 30 September, 1999 (30.09.99), Fig. 2 & AU 99/27479 A	1-10,12 11
A X	JP 10-303114 A (Nikon Corp.), 13 November, 1998 (13.11.98), Fig. 4 (Family: none)	1-10,12-14 11
A X	JP 6-168866 A (Canon Inc.), 14 June, 1994 (14.06.94), Fig. 2 & EP 605103 A1 & US 5610683 A & DE 69321571 E	1-10,12-14 11

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"&" document member of the same patent family

Date of the actual completion of the international search 29 November, 2004 (29.11.04)	Date of mailing of the international search report 14 December, 2004 (14.12.04)
Name and mailing address of the ISA/ Japanese Patent Office	Authorized officer
Facsimile No.	Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2004/015619

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 4-330961 A (Matsushita Electronics Corp.), 18 November, 1992 (18.11.92), Full text; all drawings (Family: none)	1-14

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(74) Agent: **DEGUELLE, Wilhelmus, H., G.**; Philips Intellectual Property & Standards, Prof. Holstlaan 6, NL-5656 AA Eindhoven (NL).

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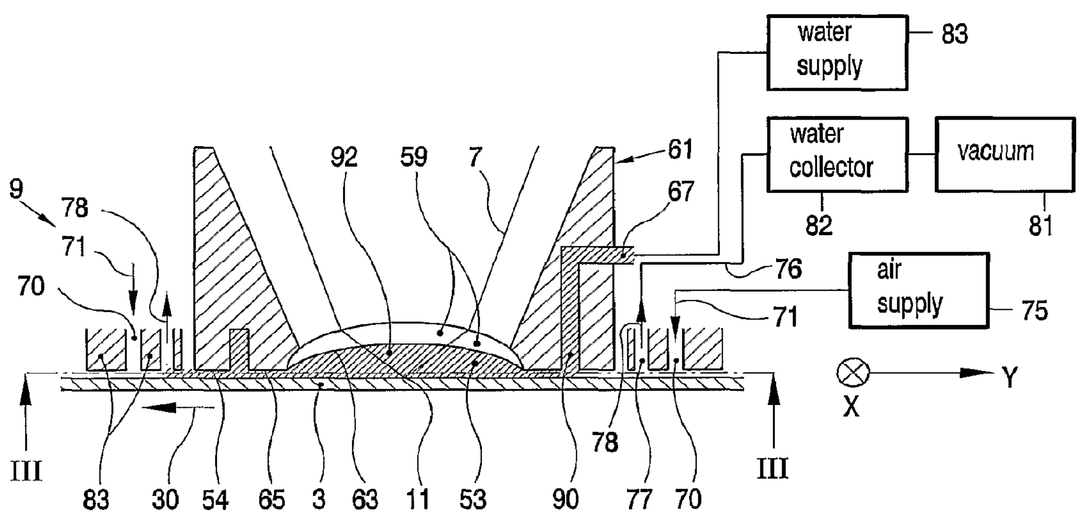
Declaration under Rule 4.17:
— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii)) for the following designations AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ,*

[Continued on next page]

(54) **Title:** LIQUID REMOVAL IN A METHOD AND DEVICE FOR IRRADIATING SPOTS ON A LAYER



(57) **Abstract:** For irradiating a layer (3) a radiation beam (7) is directed and focused to a spot (11) on the layer (3), relative movement of the layer (3) relative to the optical element (59) is caused so that, successively, different portions of the layer (3) are irradiated and an interspace (53) between a surface of the optical element (59) nearest to the layer (3) is maintained. Furthermore, at least a portion of the interspace (53) through which the radiation irradiates the spot (11) on the layer (3) is maintained filled with a liquid (91). By directing a gas flow (71-73) to a surface zone (74) of the layer (3), liquid (91) is reliably prevented from passing that surface zone (74), without causing damage to the layer (3). The liquid (91) is drawn away from the layer (3) in the vicinity of the surface zone (74).

WO 2004/055803 A1

TM, TN, TR, TT, TZ, UA, UG, UZ, VC, VN, YU, ZA, ZM, ZW, ARIPO patent (BW, GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG)

Published:
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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

Liquid removal in a method and device for irradiating spots on a layer

The invention relates to a method of irradiating a layer according to the introductory portion of claim 1 and to a device for irradiating a layer according to the introductory portion of claim 7.

In several embodiments of liquid immersion in dynamic systems, liquid immersion is maintained through continuously supplying liquid. A liquid film is maintained between the lens and the object by constantly supplying liquid through a first supply conduit, e.g. a hole, just upstream of the immersion lens at a sufficiently high pressure to avoid gas inclusion. The moving surface pulls the liquid to the image field, herewith ensuring the imaging field to be immersed. Even though with a careful design of the immersion system liquid flow can be kept low, still continuously liquid is supplied. For stable continuous operation, it is advisable to remove the liquid.

In WO-A-02/13194 a method and a system of the initially identified type are proposed to remove the liquid, related to liquid immersion mastering of optical discs. According to this publication, first a master mold is manufactured, and then, by means of the master mold or by means of a daughter mold manufactured by means of the master mold, an optically scannable information carrier is manufactured by means of a replica process. For manufacturing the master mold, a modulated radiation beam which is directed and focused to a scanning spot on a photosensitive layer carried by a substrate by means of an optical lens system and the substrate and the lens system are moved relatively to each other. An interspace between the photosensitive layer and a nearest surface of a lens system facing the photosensitive layer is maintained filled up with a liquid.

For moving the substrate relative to the lens system a table carrying the substrate is rotated about an axis of rotation. By means of a displacement device, the lens system can be displaced with a radial directional component with respect to the axis of rotation of the table. A liquid supply means supplies the liquid into the interspace between the photosensitive layer and a nearest optical surface of the lens system.

Another method and device for directing a radiation beam to a spot on a photosensitive layer, in which an interspace between the lens and the layer is maintained filled with liquid is disclosed in JP-A-10255319.

It is also known to maintain a gap between a lens and a surface to be irradiated filled with a liquid in optical imaging methods and apparatus, such as optical projection lithography, in which the spot formed by the radiation projected onto the surface is an image or a part of an image. Such a method and apparatus are described in international patent application WO99/49504.

The liquid immersion in dynamic systems, such as wafer steppers in optical lithography and mastering machines in optical disc manufacturing may be maintained by a continuous supply of liquid. Preferably, a liquid film is maintained between the lens and the object by constantly supplying liquid through a hole just upstream of the immersion lens at a sufficiently high pressure to avoid gas inclusion. The moving surface entrains the liquid to the image field, ensuring that interspace between the imaging field (the spot) and the optical element closest thereto is maintained immersed. Even though with a careful design of the immersion system liquid flow can be kept low, still continuously liquid is supplied. For stable continuous operation, it is advisable to remove the liquid. However, a key problem is to break up the adhesive forces between the liquid and the substrate surface without damaging the surface of the substrate. The substrate layer is often very delicate, for instance a soft resist layer.

Imaging systems such as wafer steppers and optical disc mastering equipment usually are very sensitive to mechanical disturbances. Varying forces exerted by the liquid film easily cause undesirable vibrations, which disturb the precision with which the image is projected onto the surface.

It is an object of this invention to reliably remove liquid of a thin liquid film from a substrate without damaging the surface and minimizing mechanical disturbances, in an imaging system for irradiating a surface, such as for example wafer steppers and optical disc mastering equipment.

According to the invention, this object is achieved by providing a method according to claim 1. Also according to the invention, a device according to claim 7 is provided for carrying out a method according to claim 1.

Using a gas flow directed towards the layer, adhesion between the liquid and the layer can be broken up very effectively, without damaging the layer and the liquid can be removed easily from the vicinity of the gas flow where the adhesion is broken up. The gas flow pushes the liquid from the disc. An additional advantage of this system is that most non-sticking particles will be removed too.

Also according to the invention, the gas may be pumped through a second supply conduit at a pressure sufficiently high to cause a net gas flow in the direction opposite to the direction of relative movement of the layer in order to remove the liquid from the layer through a drainage conduit.

Particular embodiments of the invention are set forth in the dependent claims. Other objects, features and effects as well as details of this invention appear from the detailed description of a preferred form of the invention.

Fig. 1 is a schematic side view of an example of a device for directing radiation to a spot on a layer;

Fig. 2 is a schematic, cross-sectional view of a distal end portion of an example of an optical system for a device as shown in Fig. 1, of a layer to which the radiation is directed and of a liquid flow maintained in operation;

Fig. 3 is a schematic, bottom view along the line III-III in Fig. 2;

Fig. 4 is an enlarged representation of a portion of Fig. 2 including the zone to which a gas flow is directed;

Fig. 5 is a schematic top plan view representation of a wafer stepper/scanner for optical lithography.

In the manufacture of an optically scannable information carrier, such as a CD or a DVD, a disc-shaped substrate 3 of glass (see Fig. 1) carrying a thin photosensitive layer 5 on one of its two sides is irradiated by means of a modulated radiation beam 7, for instance a DUV laser beam with a wavelength of approximately 260 nm. According to the example shown in Fig. 1, the photosensitive layer 5 is irradiated using a device 25, which is described hereinafter with reference to Figs. 1-4. The radiation beam 7 is focused to a scanning spot 11 on the photosensitive layer 5 by an optical system in the form of a lens system 9, including a plurality of optical elements. The lens system 9 includes a most distal lens 59, which is the

one of the optical elements of the lens system 9 that is located nearest to the layer 5 when in operation. An interspace 53 is maintained between the layer 5 that is irradiated and the one 59 of the optical elements of the lens system 9 that is located nearest to the layer 5. The optical elements may also include other items than lenses, such as filters, shields, diffraction gratings or mirrors.

The layer 5 and the lens system 9 are displaced with respect to each other, so that the modulated radiation beam 7 on the photosensitive layer 5 successively irradiates a series of spots on the layer 5. The irradiated photosensitive layer 5 is subsequently developed by means of a developing liquid, which dissolves the irradiated portions and leaves the non-irradiated portions of the layer on the substrate 3. It is also possible to provide that the irradiated portions are left while the non-irradiated portions are dissolved. In both cases, a series of pits or bumps, which corresponds to the desired series of pit-shaped information elements on the information carrier, are formed in the photosensitive layer 5. The photosensitive layer 5 is subsequently covered with a comparatively thin layer of for instance nickel by means of a sputtering process. Subsequently, this thin layer is covered with a comparatively thick nickel layer in an electro deposition process. In the nickel layer, which is eventually removed from the substrate 3, the pattern of pits formed in the photosensitive layer 5 leaves a corresponding pattern that is a negative of the pattern to be formed in the information carrier to be manufactured, i.e. the master mold comprises a series of raised portions, which correspond to the series of pit-shaped elements formed in the photosensitive layer 5 and to the desired series of pit-shaped information elements on the information carrier. The master mold is thus rendered suitable for use as a mold in an injection-molding machine for injection molding the desired information carriers. Generally, however, a copy of the master mold is used as the mold for injection molding instead of the master mold, which copy of the master mold is commonly referred to as daughter mold, which is manufactured by means of the master mold using a customary replica process which is known per se.

The substrate 3 with the photosensitive layer 5 is carried by a table 27 that is rotatable about an axis of rotation 29, which extends perpendicularly to the table 27 and the substrate 3. The table can be driven by means of a first electromotor 31. The device 25 further comprises a radiation source 33, which, in the example shown, is a laser source, which is secured in a fixed position to a frame 35 of the device 25. It is observed that, as an alternative, the radiation may also be obtained from outside the device. Control over the radiation directed to the layer 5 can be achieved in many ways, for instance by controlling the

radiation source 33 and/or by controlling a shutter or radiation diverter (not shown) between the radiation source 33 and the layer 5.

The optical lens system 9 is secured onto a first traveler 37, which can be displaced radially (parallel to the X-direction in the drawings) relative to the axis of rotation 29, by means of a first displacement structure 39. For this purpose, the first displacement structure 39 includes a second electromotor 41 by means of which the first traveler 37 can be displaced over a straight guide 43, which extends parallel to the X-direction and is fixed relative to the frame 35.

A mirror 45 in line with an optical axis 49 of the lens system 9 is also secured to the first traveler 37. In operation, the radiation beam 7 generated by the radiation source 33 follows a radiation beam path 47 extending parallel to the X-direction, and the radiation beam 7 is deflected by the mirror 45 in a direction parallel to the optical axis 49 of the lens system 9. The lens system 9 can be displaced in the direction of its optical axis 49 by means of a focus actuator 51, over comparatively small distances with respect to the first traveler 3, so that the radiation beam 7 can be focused on the photosensitive layer 5. The table 27 with the substrate 5 is rotated about the axis of rotation 29 at a comparatively high speed by means of the first motor 31, and the lens system 9 is displaced parallel to the X-direction by means of the second motor 41 at a comparatively low speed, so that the scanning spots 11 where the radiation beam 7 hits the layer form a spiral-shaped trail over the photosensitive layer 5 of irradiated and non-irradiated elements.

The device 25 can suitably be used to manufacture master molds having a comparatively high information density, i.e. by means of the device 25, a comparatively large number of irradiated elements can be provided per unit area of the photosensitive layer 5. The attainable information density increases as the spot 11 is smaller. The size of the spot 11 is determined by the wavelength of the radiation beam 7 and by the numerical aperture of the lens system 9, the numerical aperture depending upon the optical refractive index of the medium present between the lens system 9 and the photosensitive layer 5. A smaller size of the spot 11 is attainable as the refractive index of the medium present between the lens system 9 and the photosensitive layer 5 is larger. Liquids typically have a much larger optical refractive index than air and therefore the portion of the interspace 53 between the lens system 9 and the photosensitive layer 5 through which the beam 7 extends is maintained filled with a liquid - according to this example water. In the present example, water is also particularly suitable because it is transparent to the DUV radiation beam 7 used and it does

not attack the photosensitive layer 5. However, throughout the present detailed description, where water is mentioned it may also be replaced by any other suitable liquid.

Figs. 2 and 3 show, in more detail, the lens system 9, the substrate 3 with the photosensitive layer 5, and the interspace 53 between the photosensitive layer 5 and the lens system 9. The lens 59 nearest to the layer 5 has an optical surface 63 facing the substrate 3 and nearest to the substrate 3. The lenses 55, 59 are suspended in a housing 61, which includes a flat surface 65, which faces the layer 5 and which substantially extends in a plane perpendicular to the optical axis of the lens 59 nearest to the layer 5.

In operation, the portion of the interspace 53 through which the radiation 7 irradiates the spot 11 on the layer 5 is maintained filled with water 91. The water 91 is, at least to some extent, protected against being entrained from the interspace 53 in a recess 92 in the lens system 9 facing the layer 3.

The optimum working distance between the layer 5 and the wall 65, i.e. the portion of the lens assembly nearest to the layer 5, is determined by two factors. On the one hand, the distance should be large enough to retain sufficient tolerance on the distance between the substrate 3 and arrangement of the lenses 55, 59 and the housing 61. On the other hand, this distance should not be too large, because this would require a too large water flow to maintain the immersed condition of the portion of the interspace 53 through which the radiation passes to the spot 11. A presently preferred range for the smallest thickness of the interspace 53 is 3 - 1500 μm and more preferably 3 - 500 μm. Larger values for the smallest thickness of the interspace can be particularly advantageous if the liquid has a larger viscosity than water. Also the overall width of the outflow opening affects the upper end of the preferred range for the smallest thickness of the interspace, the smallest thickness of the interspace being preferably smaller than $(100 + 1/20 * W)$μm in which W is the overall width of the outflow opening measured in a plane parallel to the layer 5. The smallest thickness of the interspace may be larger than approximately 10 μm, for instance larger than 15 μm, 30 μm or even 100 μm, to increase the insensitivity to tolerances.

The outflow opening 90, is at least to a large extent, centered relative to the portion of the interspace 53 through which radiation passes to the spot 11. Accordingly, the direction of movement of the layer 5 and the lens arrangement 9 relative to each other in the area of the spot 11 can be varied substantially without disrupting complete immersion of the portion of the interspace 53 through which the spot 11 is irradiated.

The more the direction of movement of the layer 5 and the lens system 9 parallel to the layer 5 in the area of the spot 11 can be changed without disrupting the

immersion of the portion 94 (see Fig. 3) of the interspace 53 through which the radiation actually passes, the more the device is suitable for applications in which the spot 11 needs to move over the surface of the layer in widely varying directions, such as in imaging processes in which the spot is a two-dimensional image projected to the layer 5. In such applications, the advantage of a comparatively large refractive index between the lens system and the medium between the lens system and the irradiated surface is that the image can be projected with a higher resolution, which in turn allows further miniaturization and/or an improved reliability.

An example of such applications is optical projection lithography for the processing of wafers for the manufacture of semiconductor devices. An apparatus and a method for this purpose are schematically illustrated in Fig. 5. Wafer steppers and wafer scanners are commercially available. Accordingly, such methods and apparatus are not described in great detail, but primarily to provide an understanding of water immersion as proposed in the present application in the context of such optical imaging applications.

The projection lithography apparatus according to Fig. 5 includes a wafer support 12 and a projector 13 having a lens assembly 14 above the wafer support 12. In Fig. 5, the wafer support 12 carries a wafer 15 on which a plurality of areas 16 are intended to be irradiated by a beam projecting an image or partial image of a mask or reticle 17 in a scanner 18 operatively connected to the projector 13. The support table is moveable in X and Y direction along spindles 19, 20 driven by spindle drives 21, 22. The spindle drives 21, 22 and the scanner 18 are connected to a control unit 23.

Usually one of the following two principles of operation is applied in optical lithography. In the so-called wafer stepper mode, the projector projects a complete image of the reticle onto one of the areas 16 on the wafer 15. When the required exposure time has been reached, the light beam is switched off or obscured and the wafer 15 is moved by the spindle drives 21, 22 until a next area 16 of the wafer is in the required position in front of the lens assembly 14. Dependent on the relative positions of the exposed area and the next area to be exposed, this may involve relatively quick movement of the lens assembly 14 along the surface of the wafer in widely varying directions. The size of the irradiated spot on the surface of the wafer in which the image of the reticle is projected is typically about 20 x 20 mm, but larger and smaller spots are conceivable.

In particular when it is desired to manufacture larger semiconductor units, it is advantageous to project the image in the other mode, usually referred to as the wafer scanner mode. In that mode, only a slit-shaped portion of the reticle is projected as a slit shaped spot

having a length that is several (for instance four or more) times larger than its width in an area 16 on the surface of the wafer 15. A typical size for the spot is for instance 30 x 5 mm). Then, the reticle 17 to be scanned is moved along the scanning window while the wafer support 12 is synchronously moved relative to the lens assembly 14 under control of the control unit 23 with a velocity adapted so that only the projection spot, but not the scanned partial image portions of the reticle 17 that are projected on the wafer move relative to the wafer 15. Thus, the image of the reticle 17 is transferred to an area 16 of the wafer as successive portions "unroll" as the spot progresses over the wafer. The movement of the wafer 15 relative to the lens assembly 14 while a running window portion of the reticle is projected onto the wafer 15 is usually carried out relatively slowly and usually each time in the same direction. After the complete image of a reticle 17 has been projected onto the wafer 15, the wafer 15 is generally moved much more quickly relative to the lens assembly 14 to bring a next area of the wafer 15, where a next image of the reticle 17 is to be projected, in front of the lens assembly 14. This movement is carried out in widely varying directions dependent on the relative positions of the exposed area 16 of the wafer 15 and the next area 16 of the wafer 15 to be exposed. To be able to recommence irradiating the surface of the wafer 15 after the displacement of the wafer 15 relative to the lens 14 (i.e. also the lens or the lens and the wafer may be moved), it is advantageous if the water volume in the interspace between the lens 14 and the surface of the wafer 15 through which the radiation passes is immediately filled with water after completion of that movement, so that the space is reliably immersed before radiation is recommenced.

Also for optical lithography, water can be used, for instance if the radiation is light of a wavelength of 193 nm. However, in some circumstances other liquids may be more suitable.

For supplying water 91 to the interspace 53 between the lens 59 and the layer 5, a water supply conduit 67 extends through the housing 61 and leads to an outflow opening 90. According to the present example, the outflow opening 90 has the form of a slit in a surface 54, which slit 90 is open towards the layer 5, for distributing supplied water 91 longitudinally along the slit 90 and dispensing distributed water towards the layer 5. In operation, the water 91 is distributed via the slit 90 longitudinally along that slit and the water 91 is dispensed from the slit 90 towards the layer 5. This results in a relatively wide water trace 95 and full immersion of the portion 94 of the interspace 53 through which the radiation beam 7 passes, even if the direction of movement of the lens system 9 and the layer 5 relative to each other parallel to the plane of the layer 5 is changed substantially.

The slit 90 can have various forms. In the embodiment shown in Figs. 2 and 3, the slit is formed such that the outflow opening 90 is located outside the radiation beam 7 and extends around the portion 94 of the interspace 53 through which the radiation 7 irradiates the spot 11. The cross 96 indicates the center, seen in a direction parallel to the optical axis of the lens system 9, of the total cross-sectional passage area of the outflow opening 90.

The water 91 is preferably supplied at a pressure drop between the slit 90 and the environment that is just sufficient to keep portion of the interspace 53 through which the radiation passes reliably immersed. Thus, the amount of water fed to the surface is kept to a minimum.

Furthermore, when the water 91 is dispensed via a slit-shaped outflow opening 90, the smallest thickness of the interspace 153 (in this example the distance between the layer 5 and the surface 54 of the wall portion 65) may be larger, without causing an undue risk of disrupting the immersion of the portion 94 of the interspace through which the radiation passes.

The flow rate at which the water 91 is supplied is preferably such that it can be reliably ensured that a laminar flow with an essentially linear velocity profile is present in the interspace 53. Such a flow exerts a substantially constant force on the wall 65 in which the canal 90 is provided and on the side 63 of the lens 59 nearest to the layer 5. As a result, the water present in the interspace 53 exerts substantially no variable water forces on the lens system 9. Such varying water forces may lead to undesirable vibrations of the lens system 9 and hence to focusing errors and positioning errors of the radiation beam 7 on the photosensitive layer 5. The flow is preferably free of air inclusions, so that the radiation beam 7 is not disturbed.

The water that has been supplied to the layer 3 also has to be removed. The key problem herein is to break up the adhesive forces between the liquid and the surface. In particular when the surface moves fast, such as during the manufacture of masters for manufacturing optical discs, or during movement of a wafer between positions where reticles are to be created, this break-up requires large forces. The surface of the layers, however, usually is very delicate, often a soft resist layer. Moreover, imaging systems such as wafer steppers and optical disc mastering equipment usually are very sensitive to mechanical disturbances. Two phase flow of liquid and gas, which is difficult to avoid in dynamic liquid immersion systems usually is accompanied by mechanical disturbances.

A presently most preferred embodiment of an arrangement and method according to the invention for removing the thin liquid film without damaging the surface while minimizing mechanical disturbances is illustrated in Figs. 2 and 3.

An air outflow opening 70 is provided for directing an airflow (arrows 71, 72, 73) to a zone 74 of said layer 3 preventing water 91 from passing that zone 74. According to the present example, the air outflow opening communicates with an air supply source 75 as is schematically shown in Fig. 2. The air supply source 75 may for instance include a ventilator or an air pump and may include a reservoir in which air is stored under pressure. Instead of air, the reservoir may also contain a specific gas or mixture of gases. Furthermore, an arrangement for detecting the flow rate of the air, such as a valve or a heated wire and a control valve for controlling the flow rate in accordance with differences between the measured flow rate and the desired flow rate may be provided.

The airflow is preferably supplied at a pressure sufficiently high to cause a net airflow in a direction along the layer 3 opposite to the direction 30 of the movement of the layer 3 relative to the optical system 9. It is thus ensured that water is pushed off the layer 3 and does not reach the portion of the zone 74 where the airflow 71 is bent in different directions 72, 73 and where water might also be urged away from the immersed interspace 53 instead of being restrained to stay in an area closely about the immersed interspace 53.

Furthermore, a discharge channel 76 having an inlet 77 in the vicinity of the air outflow opening 70, and therefore of zone 74, is provided for drawing away (arrows 78, 79, 80) water 91 from the layer 3.

In operation, the airflow 71-73 that is directed to the zone 74 of the layer 3 prevents water 91 from passing that zone 74 by breaking up the adhesion between the water 91 and the layer 3 and forming a barrier in which the pressure is high enough to prevent the water 91 from passing through the zone 74. At the same time, in the vicinity of the zone 74, the water 91 that is prevented from passing the zone 74 is drawn away from the layer 3 via the discharge channel 76. Thus, the initial separation of water 91 from the layer 3 by blowing the water off the layer 3 in the area of the zone 74 is followed by discharge of that water via the discharge channel 76. Since the water 91 is separated from the layer 3 by airflow, the risk of causing damage to the layer 3 is virtually non-existent.

The air outflow opening 70 for directing the airflow 71-73 is a slit. This allows to direct the airflow towards the layer along an elongate zone which is particularly effective for preventing water 91 from displacing away from the optical system 9 beyond the zone 74, in particular if at least a portion of the slit 70 extends transversely to the direction of

movement 30 of the layer 3 relative to the optical system 9. The movement of the layer 3 in the direction 30 then entrains the water 91 applied to the layer 3, until it reaches the zone 74 where the airflow 71-73 is directed towards the layer 3. There the airflow 71-73 causes the water 91 to be separated from the layer 3 and the separated water is drawn away from the layer 3.

As is best seen in Fig. 3, the air outflow opening 70 and the inlet 77 of the discharge channel 76 extend about the interspace 53 between the layer 3 and the closest one 59 of the lenses of the optical system 9 that is maintained filled with water. This allows to reliably prevent applied water 91 from escaping from the area under the optical system 9 independently of the direction (parallel to the layer 3) in which the layer 3 is moved, without having to resort to more complicated and/or less rigid alternative solutions, such as directing the airflow selectively from one or more of a plurality of outflow openings or rotating an outflow head about the optical axis of the lens system 9 to keep the outflow opening in a position downstream of the immersed interspace. The circular shape of the air outflow slit 70 and the inlet slit 77 provides for an even distribution of the air outflow and of the suction completing the removal of water from the layer 3.

As is schematically indicated in Fig. 2, the discharge channel 76 connects to vacuum source 81 that maintains a flow 78 through the discharge channel. As is also schematically indicated in Fig. 2, the discharge channel 76 extends through a water collector 83 in which the water removed from the layer 3 is separated from the airflow and may be collected or discharged.

The airflow and can be reduced by reducing the height of the interspace between the layer 3 and a boundary surface 83 facing the layer into which the airflow is introduced. In turn, this is advantageous for reducing disturbances caused by the two-phase flow system. However, a flying height smaller than 2 μm requires very tight tolerances. Therefore, the airflow 71 is entered into an interspace between the layer 3 and a boundary surface 83 having a width (measured perpendicular to the layer 3) of at least 2 μm and preferably at least 5 μm and at most 100 μm and preferably about 30 μm.

The water 91 forms a film on the layer 3 having a thickness, and wherein an interspace 86 between the layer 3 and a surface 87 facing the layer 3 upstream of the discharge channel 76, where the water is discharged, is larger than the thickness of the film. This facilitates the flow of water towards the discharge channel 76 and reduced the pressure at which air needs to be supplied to reliably ensure that no water passes beyond the zone 74.

The displacement of water at a relatively moderate flow rate of the air supply is also enhanced by drawing away water and air from the layer 3 at a higher flow rate than the sum of the flow rates at which air and water are supplied via the channels 67 and 70. Thus, all or virtually all air that is supplied via the channel 70 is drawn towards water and a relatively moderate air supply pressure is sufficient to ensure that all water is lead to the discharge channel 76. The discharge channel 76 has a capacity larger than the water and net upstream gas flow to avoid chaotic splashing at the air-water interface. In the direction perpendicular of the movement of the substrate and in the plane of the substrate, the size of the slit and discharge channel 76 are preferably at least the size of the liquid film.

Putting the gas supply hole close to the vacuum channel can reduce the required gas pressure. Additional advantage of this system is that most non-sticking particles will be removed too.

A constant and low flying height may be achieved by mounting the proposed mechanism to an air bearing. Provided that the layer 3 is sufficiently flat, this allows maintaining a constant and low height without damaging the surface of the layer 3. The proposed mechanism may even be integrated within the air bearing, utilizing the high-pressure channel of the air bearing to push of the water off the surface of the layer 3.

The air supply channel 70 and the water discharge channel 76 extend through a structure that is rigidly connected to the lens system 9, automatically ensuring that the flying height is kept constant. To avoid the transfer of mechanical vibrations in the water removal system to the lens system 9, it may, however, be advantageous to only have a weak connection or axial guidance between the structure containing the air supply channel 70 and the water discharge channel 76, in particular if the supplied air ensures that the distance between the surfaces 83 facing the layer 3 and the layer 3 are maintained within a range suitable for ensuring complete water displacement and avoiding contact with the surface of the layer 3.

CLAIMS:

1. A method of irradiating a layer (3) including:

directing and focusing a radiation beam (7) to a spot (11) on said layer (3) by means of at least one optical element (59);

causing relative movement of the layer (3) relative to said at least one optical element (59) so that, successively, different portions of the layer (3) are irradiated and an interspace (53) between a surface of said at least one optical element (59) nearest to said layer (3) is maintained; and

maintaining at least a portion of said interspace (53) through which said radiation irradiates said spot (11) on said layer (3) filled with a liquid (91) supplied via a supply conduit;

characterized by directing gas (71-73) to said layer (3); and

removing supplied liquid (91) from said layer (3) in the vicinity of a flow of said gas (71-73).

2. A method according to claim 1, wherein said gas (71-73) is supplied at a pressure sufficiently high to cause a net gas flow (71-73) in a direction along said layer (3) opposite to the direction (30) of said movement of said layer (3).

3. A method according to claim 1 or 2, wherein the flow of said gas (71-73) is entered into an interspace between said layer (3) and a boundary surface (83) having a width of at least 2 μm and preferably at least 5 μm and at most 100 μm and preferably 30 μm.

4. A method according to claim 3, wherein the liquid (91) forms a film on said layer (3) having a thickness, and wherein an interspace (86) between said layer (3) and a surface (87) facing said layer (3) upstream of an area where the liquid is discharged is larger than the thickness of said film.

5. A method according to any one of the preceding claims, wherein liquid (91) and gas are drawn away from said layer (3) at a higher flow rate than the sum of the flow rates of said gas flow (71-73) and the supply of said liquid (91).

6. A method according to any one of the preceding claims, wherein said gas (71-73) is air.

7. A device for directing radiation to a layer (3) including:

at least one optical element (59) for focusing a beam (7) of radiation originating from a radiation source (33) to a spot (11) on said layer (3);

a displacement structure for causing relative movement of the layer (3) relative to said at least one optical element (59) so that, successively, different portions of the layer (3) are irradiated and an interspace (53) between said layer (3) and a surface of said at least one optical element (59) nearest to said spot (11) is maintained; and

an outflow opening for supplying liquid (91) to at least a portion of said interspace (53) through which, in operation, said radiation irradiates said spot (11) on said layer (3);

characterized by a gas outflow opening (70) for directing a gas flow (71-73) to said layer (3); and

a discharge channel (76) having an inlet (77) in the vicinity of said gas outflow opening (70) for drawing away liquid (91) from the layer (3).

8. A device according to claim 7, wherein said gas outflow opening (70) for directing said gas flow (71-73) is a slit.

9. A device according to claim 7 or 8, wherein said discharge channel (76) communicates with a vacuum source (81).

10. A device according to any one of the claims 7-9, wherein said gas outflow opening (70) and said inlet (77) of said discharge channel (76) extend about said interspace (53).

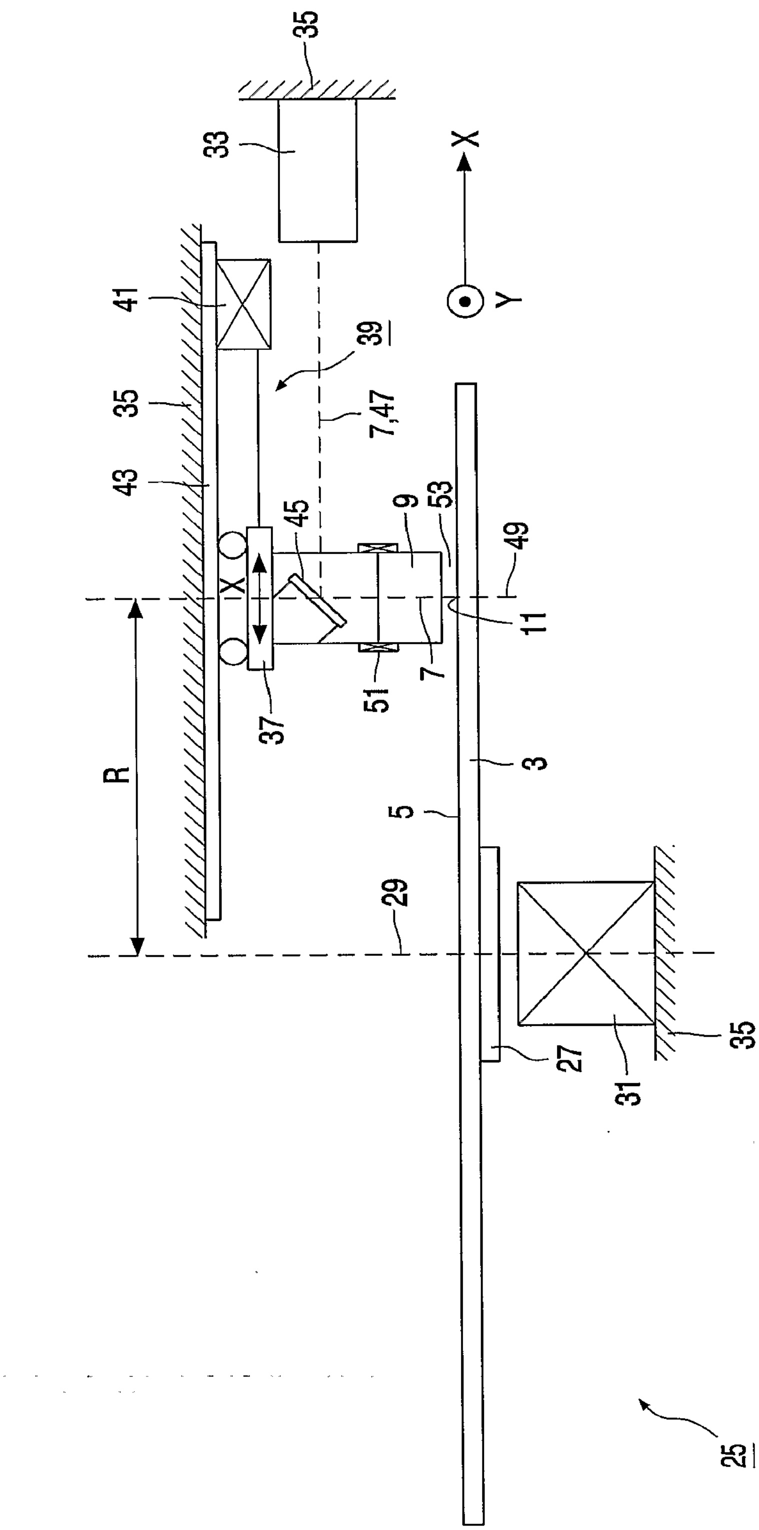
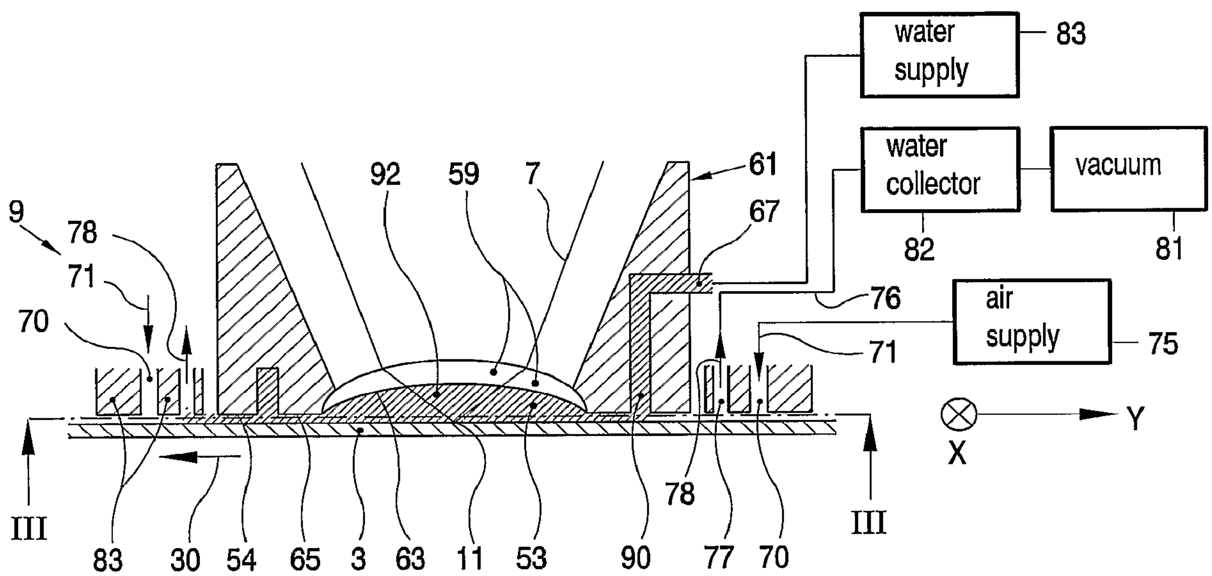


FIG. 1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water collector
vacuum
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air supply
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FIG. 2

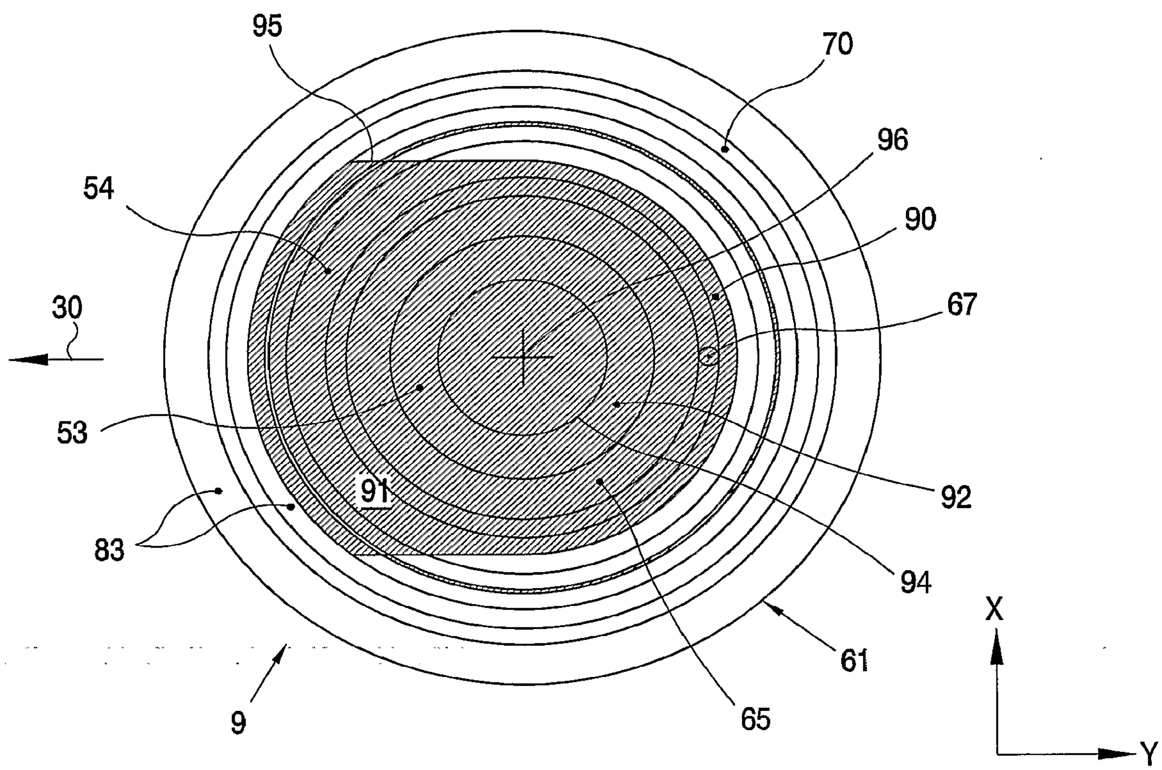
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FIG. 3

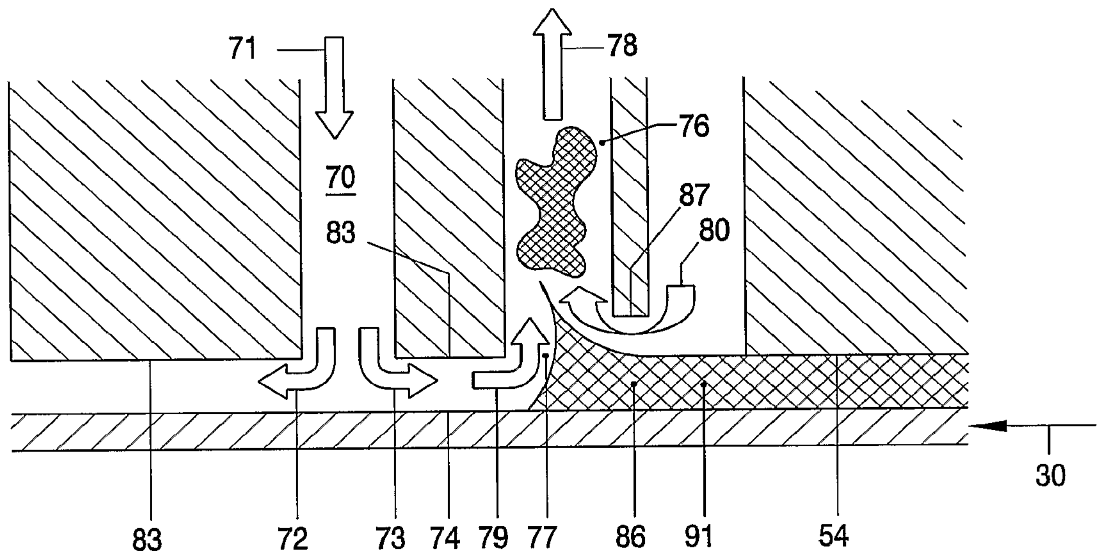
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FIG. 4

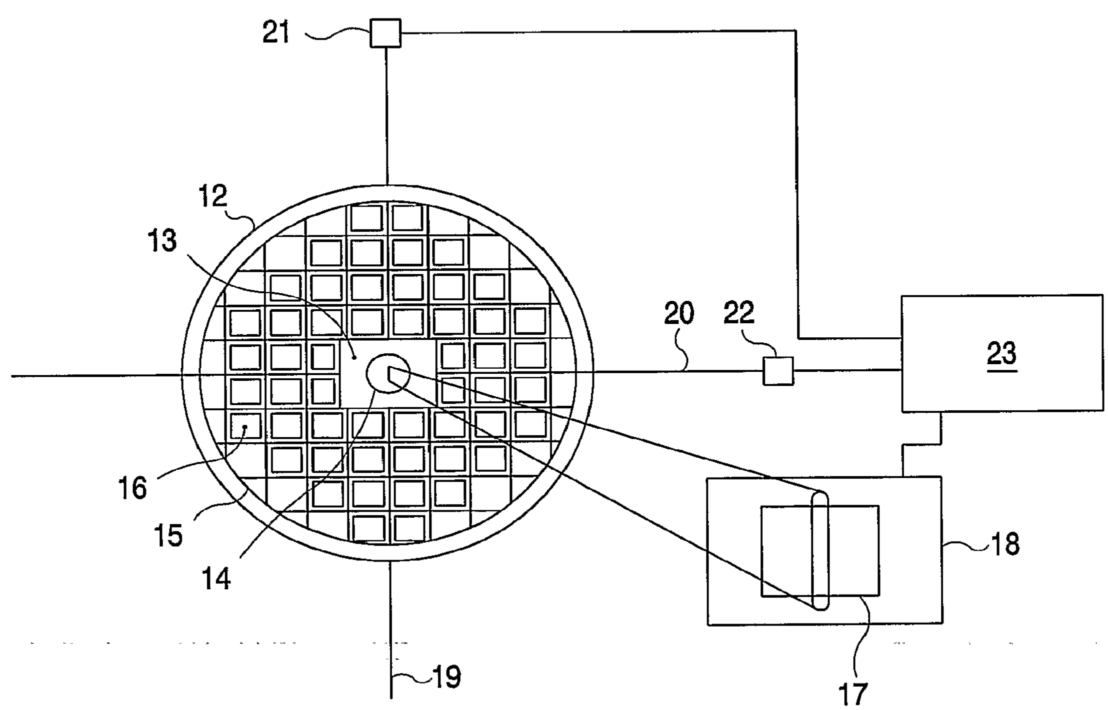
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FIG. 5

INTERNATIONAL SEARCH REPORT

In tional Application No
PCT/IB 03/05200

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G11B7/26 G03F7/20 A61N5/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G11B G03F A61N G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	the whole document ---	3-10
Y	JP 09 153233 A (SONY CORP) 10 June 1997 (1997-06-10)	1,2
A	the whole document ---	3-10
A	WO 99 49504 A (FUKAMI YOSHIO ;MAGOME NOBUTAKA (JP); NIPPON KOGAKU KK (JP)) 30 September 1999 (1999-09-30) the whole document ---	1-10
A	JP 10 255319 A (HITACHI MAXELL LTD) 25 September 1998 (1998-09-25) the whole document ---	1-10
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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
5 April 2004	19/04/2004

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Kyranos, E

INTERNATIONAL SEARCH REPORT

Int   ɔnal Application No
PCT/IB 03/05200

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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